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N.V. PHILIPS' GLOEILAMPENFABRIEKEN

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WELDING AND WELDING RODS

by J. SACK.

Summary. After a short description of the various methods of electric arc welding, the significance of the coating of the welding rod is discussed in relation to the quality of the weld.

Introduction

In the course of time various electrical processes have been developed to join metals, such as arc welding, resistance welding, spot and seam welding. In this article we shall discuss only arc welding, a method whereby the heat of an electric arc is used to join metal parts by fusion. Although in the following special attention has been paid to the welding of iron, most of the discussion applies equally well to the welding of other metals.

Typical examples of welded joints are the butt weld and the fillet weld, as represented in crosssection in *figs. 1, 2* and *3*.

Towards the end of the last century and in the present one various methods of electric arc welding were developed. The most important and most interesting of these are shown schematically in *figs. 4, 5, 6, 7* and *8*.

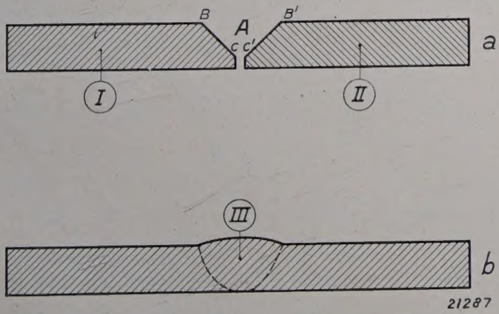

Fig. 1. Butt weld (so-called V-weld).
The sheets I and II (a), which are to be welded together, lie in the same plane. The edges of the sheets have been bevelled (BC and $B'C'$) so that a V-shaped groove is formed which is filled with molten iron. In the process the bevelled edges melt also, and the result is shown in b. In b the region III within the dotted line represents the metal which has been in a liquid state during the welding.

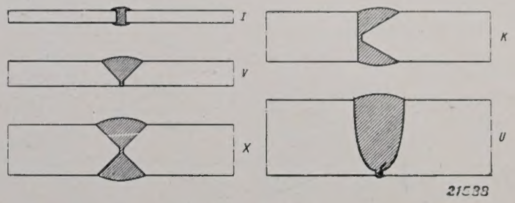

Fig. 2. Various forms of butt welds.
I-weld, V-weld, X-weld, K-weld and U-weld.

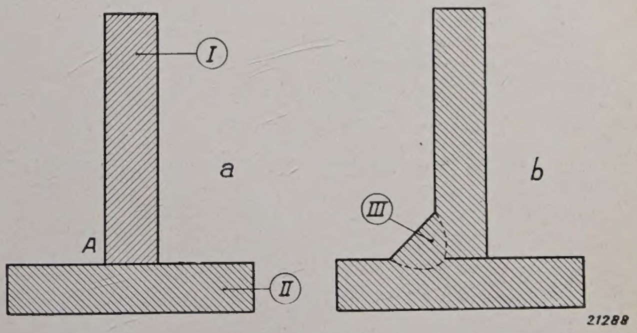

Fig. 3. Fillet weld.
In the fillet weld the parts to be joined, I and II, are perpendicular to each other. In the angle A (a) iron is melted down so that the joint b is made. Here again III represents the portion which was fluid during the welding.

The methods of Benardos (1885), Zerener (1889) and Langmuir (1926) have a certain resemblance to oxy-acetylene welding, particularly the last two; the electric arc has been substituted for the oxy-acetylene flame. Just as in gas welding, the filler rod may sometimes be omitted in electric welding. As an example, in *fig. 9* the welding of the bottom of a vessel by means of a carbon arc (Benardos method without filler rod) is represented. The edges of the bottom and sides are fused together by means of the heat of the arc.

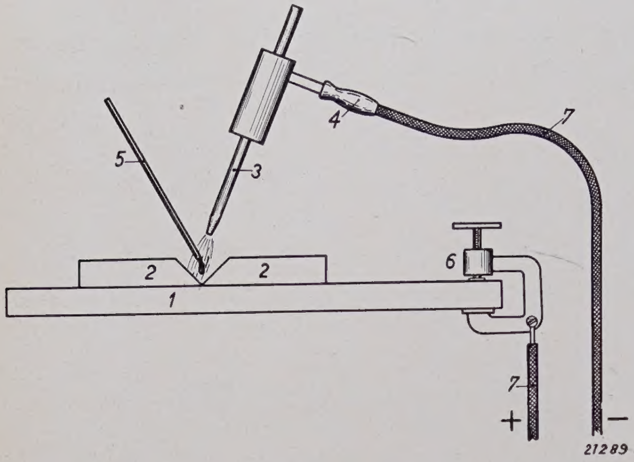

Fig. 4. Welding according to the method of Benardos (1885).

1: welding bench.
2: piece of work.
3: carbon electrode.
4: electrode holder.
5: filler rod.
6: flexible clamp.
7: flexible cables.

Between the work (*2*) and the carbon flexible (*3*) an electric arc is maintained. In the arc a filler rod (*5*) can be brought to the melting point. The molten material fills the V-shaped groove, whose edges are also melted by the arc.

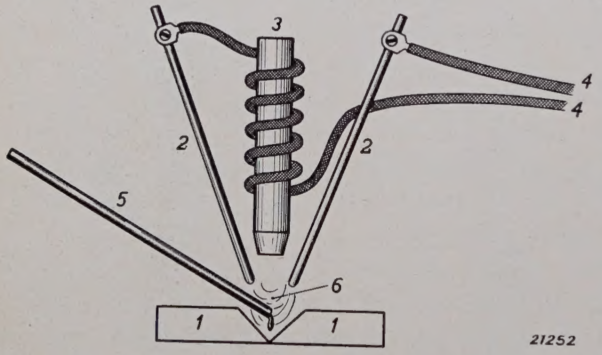

Fig. 5. Welding according to the method of Zerener (1889).

1: piece of work.
2: carbon electrodes.
3: blowing magnet.
4: flexible cables.
5: filler rod.
6: welding arc.

Zerener allowed an arc to burn between two carbon electrodes (*2*). With the aid of an electromagnet (*3*) the arc was blown toward the work. An iron filler rod (*4*) introduced into the arc melts away and fills the groove between the parts of the piece of work (*1*).

In the methods of Slavianoff (1892) and Alexander (1926) the separate electrode rod is omitted, and its place is taken by the filler rod itself, the welding rod.

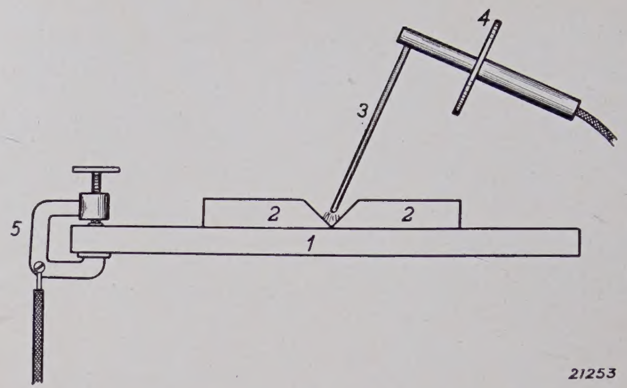

Fig. 6. Welding according to the method of Slavianoff (1892).

1: welding bench.
2: piece of work.
3: welding rod.
4: welding rod holder.
5: clamp.

The arc burns between the piece of work (*2*) and an iron electrode (*3*), the so-called welding rod. The arc causes the welding rod to melt as well as the edges of the groove. The welding rod thus performs a double function, it is electrode as well as filler rod.

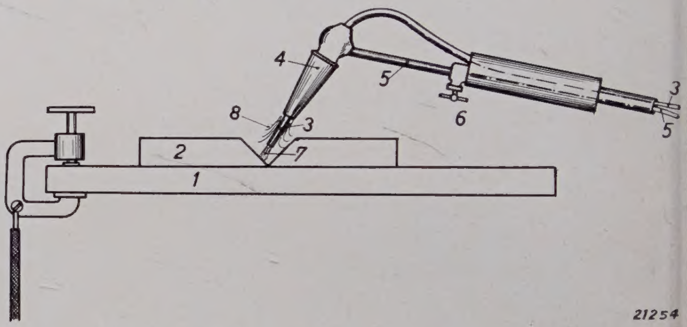

Fig. 7. Welding according to the method of Alexander (1926) (semi-automatic model)

1: welding bench.
2: piece of work.
3: welding wire, automatically fed.
4: nozzle.
5: tube for the supply of protecting gas.
6: tap for regulating the supply of gas.
7: electric arc.
8: atmosphere of protecting gas.

About the wire (*3*), which is preferably automatically fed, a protecting gas (for example, hydrogen) is blown by means of the nozzle (*4*) in order to prevent the bare welding rod from coming into contact with the oxygen and nitrogen of the air during melting. Otherwise this method is the same as that of Slavianoff.

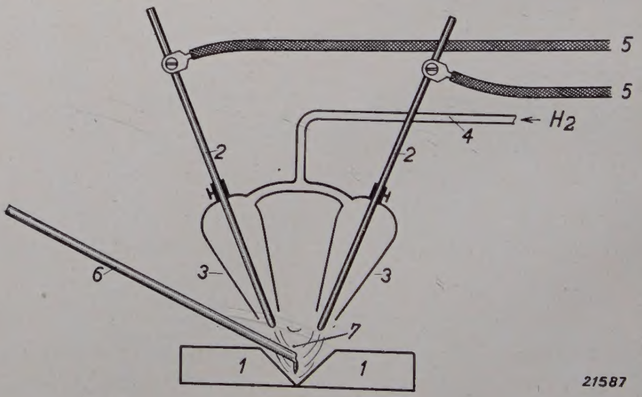

Fig. 8. Welding according to the method of Langmuir[2]) (1926).

1: piece of work.
2: tungsten electrodes.
3: nozzles for the supply of hydrogen gas.
4: tube for the supply of hydrogen gas.
5: flexible cables.
6: filler rod.
7: atomic hydrogen arc.

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[1] P. Alexander, Arc Welding in Hydrogen and other Gases, Gen. Electr. Rev. **29**, 169, 1926.

[2] R. A. Weinmann and I. Langmuir, Atomic Hydrogen Arc Welding, Gen. Electr. Rev. **29**, 160, 1926.

We shall not enter into the various advantages and disadvantages and the possibilities of application of the methods mentioned. It may however be noted that the method of Slavianoff is clearly the simplest, and is the one practically always used at present for manual welding.

Electric welding was developed extremely slowly at first, a fact which must be ascribed to the unsuitable electrical apparatus available, the slightness of metallurgic knowledge and probably also to the competition of oxy-acetylene welding. Only a few factories used electric welding, and even then exclusively for repair work. So-called bare wire, i.e. ordinary iron wire, was used for welding rods. This wire could only be welded with direct current. The generators available before 1914 were expensive and were not constructed especially for welding. A considerable advance was made by the use of coated welding rods which were introduced by the Swede Kjellberg.

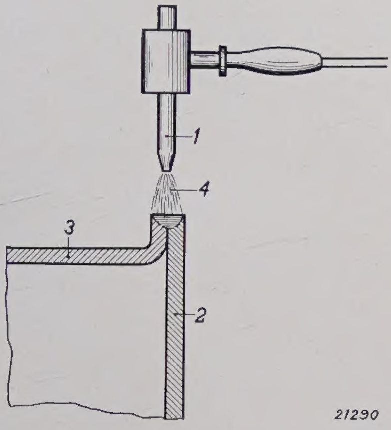

Fig. 9. Carbon are welding.
1: carbon electrode. *3*: side of vessel.
2: bottom of vessel. *4*: welding arc.

After 1918 a rapid development not only of welding machinery [3]) but also of welding rods began. Electric welding developed from a repair method into a method of construction. Much which was previously done by oxy-acetylene welding, riveting or casting, is now done with success and advantage by electric welding. This development is still going on, and, more than with any other construction method, the application of electric welding is accompanied by intensive technical and scientific research. The following will give some information about the significance of the coating of the welding rod in relation to the quality of the weld. We shall begin by discussing the welding arc.

The welding arc

Accurate determinations of the temperature of an arc have recently been carried out. The most important and most accurate method of measurung arc temperatures was worked out by Ornstein and his co-workers at the University of Utrecht [4]). The spectrum of the arc was observed and it appeared that not only the rotation spectrum but also the vibration spectrum of the molecules in the column of the arc provide the observer with sufficient data for the calculation of the temperature.

Suits [5]) follows another method. The velocity of sound in a gas is proportional to the square root of the absolute temperature of the gas. Thus it is possible to calculate the temperature of the arc from the velocity of propagation of a sound wave in the arc. The sound is manifested in the arc by an increased radiation at the place where the pressure wave is passing through (see *fig. 10*). This can be recorded on a rapidly moving film.

The temperatures found by investigators for the electric arc are surprisingly high. Suits found in the case of a welding arc between a coated welding rod with a diameter of 3/16″ as cathode and an

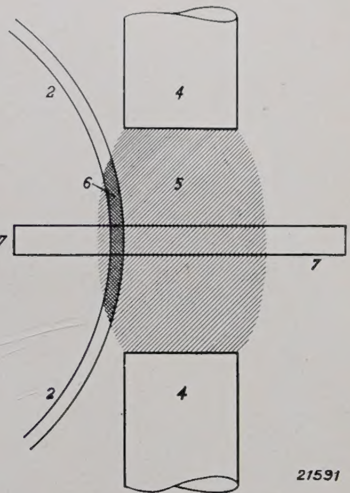

Fig. 10. Diagram showing Suits' method of measuring the temperature of an arc.
A spark discharge at (*1*) makes a report, i.e. a pressure wave (*2*) about one mm. thick. The movement of the pressure wave through the arc (*5*) between the electrodes (*4*) is visible because of an increased radiation (*6*). By means of a diaphragm only the portion (*7*) of the phenomenon is recorded on a rapidly moving film. From the measured velocity of propagation of the report through the arc the temperature of the arc may be calculated.

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[3]) H. A. W. Klinkhamer, Philips techn. Rev. **1**, 338, 1936.

[4]) L. S. Ornstein and W. R. van Wijk, Temperaturbestimmung im elektrischen Bogen aus dem Bandenspektrum, Proc. kon. Akad. Wet. A'dam, **33**, 44, 1930. L. S. Ornstein and H. Brinkman, Temperature Determination from Band Spectra, Proc. kon. Akad. Wet. A'dam, **34**, 33, 498, 1931.

[5]) C. G. Suits, A Study of Arc Temperatures by an Optical Method, Physics, **6**, 315, 1935.

iron plate as anode, with a current of 125 A and an arc-length of 1 cm, an arc temperature fluctuating between 4400 °K and 7000 °K with an average value of 6020 °K. For a welding arc between a tungsten cathode with a diameter of 3,2 mm and an iron plate, current of 80 A, arc length 0.5 cm, Suits found an average temperature of 6150 °K.

The following conclusions may be added. Oxygen and nitrogen molecules may break up into atoms (dissociation), and the dissociation probability increases with increase of temperature. At room temperature the equilibria:

$$O_2 \rightleftarrows 2\,O \quad \text{and} \quad N_2 \rightleftarrows 2\,N$$

are toward the left.

At high temperatures definite fractions of the oxygen and nitrogen molecules are dissociated. The gas mixture then consists of O_2 and N_2 molecules and O and N atoms. The partial pressure of the atomic oxygen and nitrogen as a function of the temperature is known.

At a temperature of 6000 °K 80 per cent of the atmosphere is atomic oxygen and nitrogen.

Bare welding rods

From the above it follows that with bare welding rods one actually welds in an atmosphere of "atomic air", which contains much atomic nitrogen. The presence of atomic nitrogen in the arc has been confirmed spectrographically by Séférian [6]). He showed further that nitrogen in the atomic state is readily taken up by the iron with the formation of iron nitride Fe_4N. It is therefore not surprising that the material melted down in welding with bare welding rods is very rich in nitrogen, even increasing from 0.15 to 0.16 per cent of N with a short arc (2 mm) to 0.19 to 0.20 per cent, of N with a long arc (6 to 8 mm; a longer arc presents more opportunity for the taking up of nitrogen [7]). **Portevin** and **Séférian** even make use of this material melted down from uncoated welding rods for the setting up of an improved phase diagram for the system iron-nitrogen. According to this diagram the iron can contain in solution its maximum amount of nitrogen, namely 0.14 per cent., at a temperature of 590 °C. At room temperature the solubility is, however, appreciably less: about 0.01 per cent.

If the iron contains more nitrogen than the amount soluble in it, this excess nitrogen may be precipitated as iron nitride Fe_4N, a hard component with a very bad influence on the ductility (deformability) and toughness of the material. This is seen clearly in *figs. 11* and *12*, in which the impact value (as a measure of the toughness) and the elongation (as a measure of the ductility) are plotted as functions of the nitrogen content. On the other hand the tensile strength is increased by nitrogen [8]).

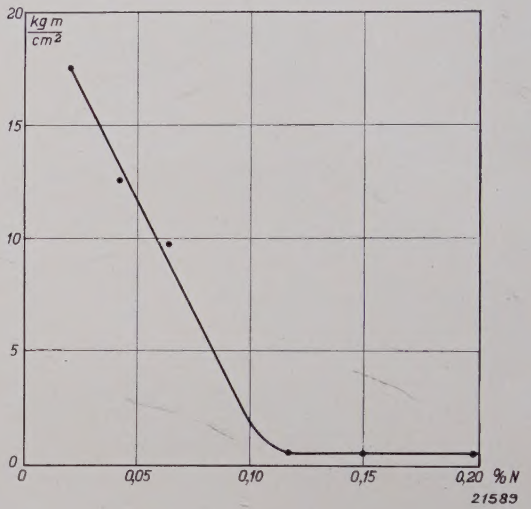

Fig. 11. The notched bar toughness of remelted iron in relation to its nitrogen content. The material was annealed at 900 °C. The notched bar toughness value is determined on notched specimens of the Mesnager model. The values are borrowed from Séférian's dissertation.

The material obtained in welding with bare wire can therefore best be described as hard and brittle, while what is desired is a material which is more or less hard and tough. In addition to the unfavourable influence of the nitrogen in welding with bare wire there is also the bad influence of the oxygen if this is present in a large amount in the weld. It has, however, been found that the mechanical properties are much more strongly influenced by nitrogen than by oxygen. While 0.25 per cent of O and more may be permissible in the weld, according to fig. 11 the impact value of a weld with about 0.06 per cent of N is about one half of that with 0.02 par cent of N.

The gases — and in this case particularly oxygen — also have an important influence on the density of the weld. Experience has shown that the material melted down from the bare welding rod is porous due to slag inclusions and blow holes. The slag inclusions consist chiefly of iron and manganese oxides, the blow holes contain carbon monoxide which is formed from the reduction of iron oxide by carbon.

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[6]) D. Séférian, Étude de la formation des nitrures de fer par fusion et du système fer-azote. Dissertation: Paris 1935.

[7]) On the other hand J. C. Hodge (The Chemistry of Low-carbon Arc Weld Metals, J. Amer. Welding Soc. **11**, 36 Oct. 1932) gives lower values, for example 0.08, 0.11 and 0.12 per cent of N.

[8]) It has been found very difficult to examine separately the influence of nitrogen and of oxygen. For that reason some investigators prefer to plot the properties as functions of the total content of $O_2 + N_2$. Thus E. Söhnchen (Gase in Lichtbogenschweißung von Stahl, Arcos **13**, 1440, (1936), finds that the tensile strength decreases with increasing content of oxygen plus nitrogen.

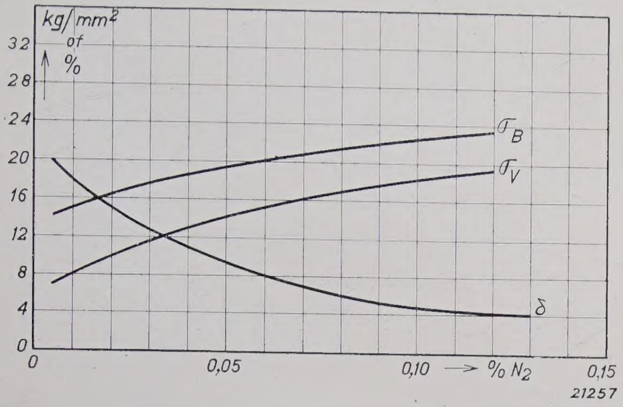

Fig. 12. Tensile strength (σ_B) and yield value (σ_V) in kg/mm², and elongation (δ) in per cent, in relation to the nitrogen content of nitride' steel wire (0.14 % C, 0.18 % Si and 0.45 % Mn) according to Tschischewski (The Occurrence and Influence of Nitrogen in Steel, J. Iron and Steel Inst. **92**, 47 1915).

In order to obtain good mechanical properties of the weld, care must be taken to prevent the material being attacked by the air during the welding process. This is done by coating the welding rods.

Coated welding rods

The coating is carried out by dipping the rods in a thin paste of ground minerals, sometimes mixed with organic substances, drying and then repeating the operation until the correct thickness of coating is reached. It is also possible to extrude the coating around the wire in one operation.

It has been shown by means of cinematographic X-ray recording 9) that the material of the welding rod is transferred to the work to be welded in the form of drops. This holds for the bare as well as for the coated welding rod. In the latter case it also appeared that the formation of the drops takes place entirely or for the most part within the coating, and that the moving drops are covered with the flux (molten coating) (*fig. 13*). The drop form of the transfer of material is shown very clearly when the welding rod is drawn rapidly over a plate. The drops are then seen to lie separately on the plate (*fig. 14*). Each drop is found to be provided with a layer of slag. Metal and slag are thus transferred simultaneously, and the flux entirely surrounds the drop of metal, making difficult in this way the entrance of gases from the atmosphere.

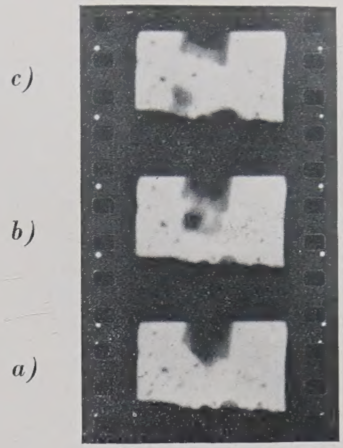

Fig. 13. Cinematographic X-ray record with 50 pictures per second of the transfer of a drop in welding:
a) drop upon formation entirely covered with flux,
b) drop passing over entirely surrounded by flux,
c) the coating forms a cup.

It is further desirable during the formation of the drop at the extremity of the rod that it be entirely covered with flux and thereby shut off from the air. The fact that this is actually the case with the Philips welding rods is proved by *fig. 15* which shows the form and condition of the coating after the interruption of the current during welding. A layer of flux shuts off the drop which is in the process of being formed from external gases.

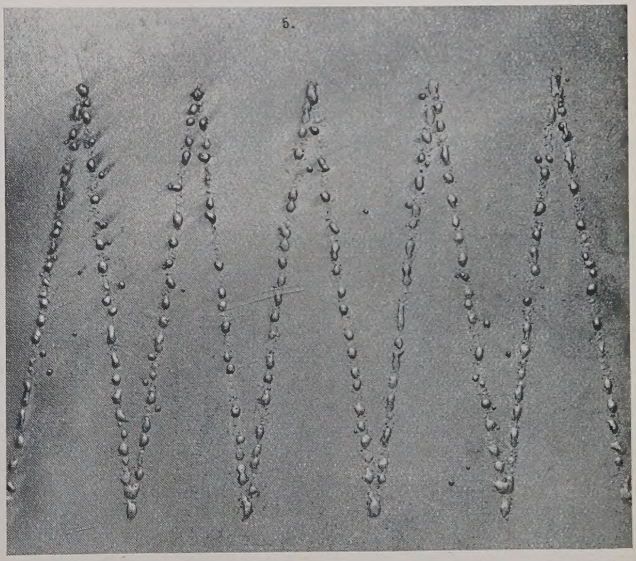

Fig. 14. Drops on an iron plate (reduced 4 times) obtained by a rapid relative movement of welding rod and plate. Automatically welded with PH-50. After welding the slag is removed and the plate is cleaned with a sand blast.

The molten metal is not only protected mechan-

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9) J. Sack. The Iron and Steel Institute, Symposium on the Welding of Iron and Steel, **2**, 553, London 1935.
J. Sack, How Does a Welding Electrode Fuse? Philips techn. Rev. **1**, 26, 1936.

ically by the flux, but it is also screened by a mantle of gas. This protecting gas which displaces the harmful gases is formed by the evaporation of the flux and by the decomposition of some of the components of the coating. In *fig. 16* the welding process is represented schematically. The drops, entirely surrounded by flux, pass over from the welding rod to the pool in the piece of work. The density of the flux, or "slag", is about half that of iron, so that in the pool the slag easily floats to the surface and shuts off the liquid metal.

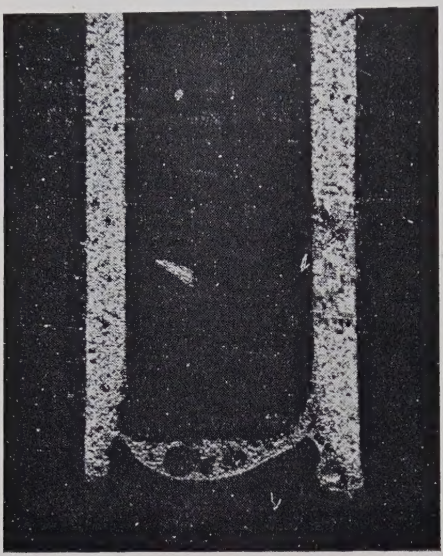

Fig. 15. Cross section of the coating after the iron core has been removed (enlarged 5 times). Condition after interruption of current during welding. A thick layer of flux covers the half-formed drop and prevents the liquid metal from being attacked by nitrogen or oxygen of the air.

It may be seen from fig. 16 that there is a fundamental analogy between what takes place in welding and what takes place in the manufacture of steel.

The melting coated welding rod and the pool are in fact miniature electric arc furnaces.

The welding process as a method of "steel manufacture"

In the steel furnace, for example a basic open hearth furnace or a Thomas converter the molten metal is covered with a layer of slag, which serves not only to protect it against oxidation by the air, but at the same time fulfils all sorts of other functions such as purifying and reacting with the metal.

In welding, the flux must also serve similar "metallurgical purposes", in order that the weld shall satisfy the various requirements which will be made of it. While, however, in an electric furnace the time during which the slag is in contact and reacting with the liquid metal, is more than an hour, during welding all the metallurgical reactions must be complete in a few seconds.

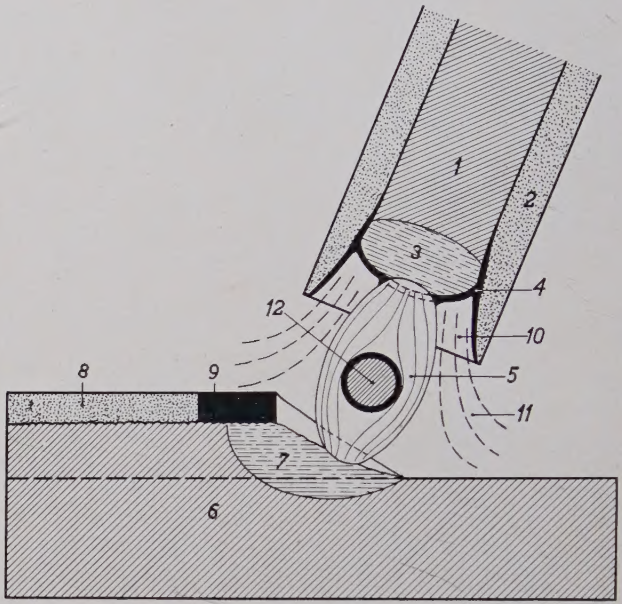

Fig. 16. Diagram of the welding process (cross section).

1: core of the welding rod.
2: coating of the welding rod.
3: drop of liquid metal (to be compared with the bath of molten metal in the manufacture of steel).
4: liquid flux (covers the molten bath 3).
5: electric arc.
6: piece of work to be welded.
7: bath of molten metal under tha arc, the so-called pool.
8: solidified flux which covers the metal already melted.
9: liquid flux.
10: cup (exerts a very favourable influence on the stability of the arc.
11: protecting gas.
12: drop in transit surrounded by flux.

This is made possible by two things:

1) During welding the temperatures are much higher than during smelting. The velocity of the reaction between slag and metal depends largely upon the temperature, and it is appreciably higher during welding than during smelting.
2) The relation of the size of the surface of contact to the amount of molten metal is, perhaps, 100 times greater in electric welding, which is more favourable to reaction than in smelting.

Other functions of the coating

The coating may have still other functions besides the above-mentioned ones:

a) It decreases the loss by oxidation and evaporation of the elements existing in the welding wire,

such as C, Mn and Si. With bare wire the oxidation [10]) of
carbon amounts to 40 to 60 per cent,
manganese ,, ,, 50 to 85 per cent,
silicon ,, ,, 100 per cent.
With coated welding rods the oxidation is dependent on the nature and thickness of the coating. If desired the loss by oxidation of an element can be compensated for by the addition of this element to the coating. Thus in the case of the Philips 50 (a thickly coated welding rod for welding mild steel) the oxidation of:
carbon is 0 per cent
manganese ,, 0 per cent,
while the content of silicon in the deposited material is higher than that of the wire.

b) The substances in the coating, especially those with a low work function, make possible the use of alternating current for welding, which is impossible with bare rods. A very thin coating is sufficient to make this possible.

c) The coating forms a cup at the extremity of the welding rod, which directs the arc (fig. 13*c*), so that the blowing of the arc due to the so-called magnetic wind is decreased. In welding with bare and thinly coated welding rods this phenomenon often gives much difficulty. Moreover the arc blow also depends upon various factors such as the intensity and nature of the current.

d) The closed cover of slag on the weld provides for a more gradual cooling of the material deposited.

Philips welding rods

The welding rods are provided in various kinds and thicknesses. For welding mild steel and wrought iron the welding rods PH-38, -40, -46 and -50 may be used. Each type has its specific range of application:

PH-38 For simple constructional work of mild steel of medium strength, and for reinforcing. Also suitable for the welding of cast iron, with and without preheating, but the junction cannot be machined.

PH-40 For constructional work of mild steel of medium strength. For welding sheet steel.

PH-46 For constructional work in which a tight, regular and smooth weld is required. For thin sheet welding, steel window frames, etc.

PH-50 For constructional work with high static and dynamic loads, such as bridges, locomotives, railway carriages and ships. Also for welding and reinforcing high-tensile steel and for maintenance welding on cast iron and malleable iron. The weld can be forged and has the following physical properties:

tensile strength . . .	29 - 33 tons/sq.in.
yield	23 - 25 tons/sq.in.
elongation ($l = 5d$) . .	27 - 31 per cent
notched bar toughness on DVM specimens . .	9 - 12 kgm/sq.cm
resistance to fatigue .	14 - 15 tons/sq.in.
angle of bending	180 degrees

For reinforcing with high resistance to wear, the welding rods PH-200, -250 and -600 can be used. The numbers are approximately the same as the Brinell hardness numerals of the layer built up.

For the welding of aluminium, bronze and cast iron (without preheating, the weld can be machined) the welding rods PH-AL, -BR and -GM may be used.

For the welding of stainless steel the following are suitable: PH-RS (especially adapted for fillet welds) and PH-RSB (especially adapted for butt welds).

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[10]) G. M. Tichodeev, Physical-chemical Phenomena of the Transfer of Metal during Welding, J. Amer. Welding Soc. **15**, 26 Mar. 1936.

[11]) K. T. H. Dag Du Rietz, Blaswirkungen bei der Lichtbogenschweißung, Elektroschweißung, **7**, 101, 1936.

THE CAUSES OF NOISE IN AMPLIFIERS

by M. ZIEGLER.

Summary. Two causes of noise in amplifiers are considered in detail: the corpuscular nature of electricity and the thermal motion of the electric charges in conductors. Both of these phenomena cause in an electric circuit fluctuations of potential and current which are evenly distributed over the whole range of frequencies. By comparing the observed fluctuations with the result of theoretical considerations it is possible to determine the elementary charge e and the Boltzmann constant k.

Introduction

When the development of radio technique, particularly that of amplifier tubes, had made possible the amplification of electric potentials to almost any desired extent, the difficulty was soon experienced that the possibility of making very weak signals observable was not exclusively limited by the presence of disturbances of "atmospheric" or industrial origin. While the level of the disturbances mentioned can, under favourable circumstances be made so low as to be neglected, a continuous noise is, however, still observed, from which very weak signals can no longer be separated.

Even by the most careful choice of the parts to be used and the most careful mounting of them, by the elimination of all fluctuations from mechanical sources, among which may be included the microphonic effect and current fluctuations due to poor contact, it is impossible to lower the level of the disturbances below a definite limit.

The phenomenon is indeed of a fundamental nature. It is a manifestation of the spontaneous irregular motion and of the corpuscular structure of electricity.

Spontaneous movement

Wherever an electric current can flow under the influence of an electromotive force, the electricity is always spontaneously in motion, even in the absence of such an EMF, because the electrons, which make conduction possible, take part in the heat motion of the atoms; in other words, they possess their own thermal velocity (this velocity which allows them to leave a heated filament, for example). The thermal movements of electrons are, like those of the molecules of a gas, entirely at random, with the result that on the average over short periods of time there will occur an excess of electron motion in the one or the other direction. One then speaks of the "thermal" fluctuations of current or voltage.

Whenever, for instance under the influence of a sinusoidal EMF, a regularly alternating swarming movement of particles of electricity is superposed upon the above-mentioned unavoidable irregular motion, the regular motion will be distinguishable only if that motion is sufficiently great compared with the irregular motion, no matter how great the amplification.

We shall see that the intensity of the thermal fluctuations is connected with the thermal energy kT, in which $k = 1.37 \times 10^{-23}$ joule/degree, the so-called Boltzmann constant, and T is the absolute temperature, and is independent of the size of the elementary charge, that is, it would be as great if this charge were infinitesimally small.

Corpuscular structure

It is known that the particles of electricity have a finite charge e, which is equal to 1.6×10^{-19} coulombs. In a vacuum tube when either by photo-emission or by thermionic emission electrons leave an electrode independently of each other, and, also independently, pass over to another electrode, then even with a strong current through the tube the number of electrons which passes over in a given interval of time is finite. This number is however not always exactly the same, but exhibits accidental fluctuations about the mean value. The fluctuations of current depending on this are determined by the size of the elementary charge e. The phenomenon is called the "shot effect" because of its analogy with the pattering of shot.

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¹) In order to make clear the significance of k it may be remarked that the average kinetic energy of a free particle taking part in the thermal motion is $3/2kT$.

Fluctuations in the number of independent events

The theoretical treatment of the shot effect is nothing but a special case of the well known problem of the calculation of the probability of fluctuations in a number of independent events. In the calculation of the thermal fluctuations of electricity one may also, as we shall see, make use of the solution of this problem. The problem in probability is the following. Assume that one is considering a series of events which occur independently of each other, for instance the passing of vehicles in a continually evenly crowded street, the births over the whole world, falling hailstones, etc. One counts the number of events during equally long, successive intervals of time. This number n will in general be different for all the intervals. We limit ourselves to those cases in which the mean of n taken over a large number of observations, which mean we call $\bar{n}$, no longer changes when the number of observations is taken still larger. The series of the differences $(n - \bar{n})$ tells us something about the fluctuations in the time of the number of events. The numbers counted may not only be larger but also smaller than $\bar{n}$. On the average, according to the definition of $\bar{n}$, the deviation $(n - \bar{n})$ from the mean will of course be 0. One may however ask what is the mean square of $(n - \bar{n})$, which is always positive. The theory of probability shows that if the n events are independent of each other, the mean square of the deviation is just equal to the mean number of events. One obtains therefore the important formula

$$\overline{(n - \bar{n})^2} = \bar{n} \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

As the time intervals are chosen longer, n and $\bar{n}$ and therefore also the mean square of the fluctuations, become greater. Relatively, the fluctuations become steadily smaller, since equation (1) can also be written

$$\overline{\left(\frac{n - \bar{n}}{\bar{n}}\right)^2} = \frac{1}{\bar{n}} \,.$$

If by n we understand the number of electrons which in a vacuum tube pass over in a given interval of time τ from one electrode to the other, formula (1) gives us a picture of the fluctuations in the current strength.

Let us consider as an example the current in the photocell in the case of a television installation described previously in this periodical [2]). If we are interested in the accidental variations in the brightness of an image point, then τ is the time of illumination for one point, and is in this arrangement 2×10^{-7} sec. The current strength in the dark parts of the picture is about 10^{-8} A $= 6 \times 10^{10}$ electrons per second, so that 10 000 electrons are emitted per element of the image. The mean square of the relative fluctuations in the intensity is thus 10^{-4}. The average variation in the brightness of an image point resulting from this is given by the square root of the square of the fluctuations, and will therefore be about 1 per cent.

Application to the shot effect

As the above example shows, equation (1) is immediately applicable to the fluctuations which occur in a vacuum tube where the chance of the transition of an electron from one electrode to the other is independent of the behaviour at that moment of the other electrons. This is for example the case in a saturated diode (see *fig. 3*).

Just as in the above described example n is the number of electrons which pass over in a given interval of time τ from the cathode to the anode. The current strength in that time interval is on an average

$$I_\tau = \frac{n\,e}{\tau} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

Now equation (1) can be written in the form

$$\overline{\left(\frac{n\,e}{\tau} - \frac{\bar{n}\,e}{\tau}\right)^2} = \bar{n}\left(\frac{e}{\tau}\right)^2,$$

from which, with the aid of (2) it follows that

$$\overline{(I_\tau - \bar{I})^2} = \frac{e}{\tau} \cdot \bar{I} \quad . \; . \; . \; . \; . \quad (3)$$

Here $\bar{I} = \bar{n}\, e/\tau$ is the mean value of the current over a very long time.

We see from this formula that the mean square of the deviation of the current so defined is determined by the charge e of the electron, and is furthermore proportional to the average current and inversely proportional to the time τ of the observation.

If we should let the time τ become infinitesimally small, then according to (3) $\overline{(I_\tau - \bar{I})^2}$ would become infinitely great. The fact that this is actually not the case is dependent on the fact that the current impulses at each transition are not infinitely short, as we have up to now tacitly assumed.

Spectral consideration of the shot effect

In equation (3) the theory of the shot effect is given, but the form of this equation is not yet such that one can immediately see from it how the shot effect will be manifested in practice. It seems however natural to consider the irregular variations of the current, which are superposed upon the mean current because of the shot effect, as composed of components with all frequencies. Actually one is of course not concerned with all frequencies at once, but with those which lie within a finite range of frequencies.

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[2]) H. Rinia and C. Dorsman, Philips techn. Rev. **2**, 72, 1937.

It is easy to understand that the proportionality of the fluctuations to $\bar{I}$, expressed in equation (3), also holds for the fluctuations included in any arbitrary range of frequencies. There is no difference in kind between the current I of one saturated diode and an equally large current coming from n saturated diodes connected in parallel, of which each one allows the current $I_l = I/n$ (where the subscript l indicates an arbitrary example of the n diodes) to pass, because both currents are built up in exactly the same way of electron transitions. It is also impossible to distinguish among the n parallel connected diodes themselves. If we represent the fluctuations included in a given frequency range by the letter i, then the following holds:

$$i = \sum_{k=1}^{n} i_k, \text{ so that } \overline{i^2} = \overline{(\Sigma\, i_k)^2}.$$

Since there is no correlation among the various currents

$$\overline{i_1\, i_2} = \overline{i_1\, i_3} = \ldots = 0,$$

so that

$$\overline{i^2} = \sum_{k=1}^{n} \overline{i_k^{\,2}} = n\, \overline{i_l^{\,2}}.$$

From this it follows that the desired proportionality is

$$\frac{\overline{i^2}}{\overline{i_l^{\,2}}} = n = \frac{\bar{I}}{\bar{I}_l}.$$

What finally is the spectral distribution of the components into which the fluctuations can be resolved? Since the fluctuations are governed entirely by change, the chance of rapid variations is just as great as of slow ones, so that it may be expected that all frequencies will be equally represented. It may, as a matter of fact, be calculated that the contribution to the mean square of the fluctuations due to the components included in the frequency range between ν and $\nu + \Delta\nu$, which component we shall indicate by $\Delta\ \overline{(I - \bar{I})^2}$, is independent of ν and proportional to the breadth of the frequency range and to the mean current:

$$\Delta\ \overline{(I - \bar{I})^2} = 2\, e\, \bar{I}\, \Delta\nu \quad . \; . \; . \; . \quad (4)$$

In the derivation of this result it is assumed that the length of time necessary for the transition of an electron is short compared with the time of vibration at the frequency ν. If this condition is no longer fulfilled, the fluctuations are smaller. Instead of (4) we then obtain

$$d\ \overline{(I - \bar{I})^2} = 2\, e\, \bar{I}\, f(\nu)\, d\nu,$$

where $f(\nu)$ is a function which, in a diode of the usual dimensions, is a constant equal to 1 up to about 10^8 per c/s, and then gradually approaches 0, so that $\overline{(I - \bar{I})^2}$ always remains finite. In the case of most of the frequencies usual in the radio one is still concerned with formula (4).

The discussion up to now has referred to the case of the saturated diode. If the current of electrons in a vacuum tube is not saturated, that is if the current strength is determined by the space charge (thus by the mutual repulsion of the electrons), then the shot effect becomes appreciably smaller. In this latter case the transitions of the electrons are no longer independent of each other. A chance excess of emitted electrons is reflected back to the cathode by the space charge, so that the number of electrons passing over exhibits much less variation. Because of this fortunate circumstance the fluctuations of the current in radio tubes, where there is always an appreciable space charge around the cathode, is considerably less than would follow from formula (4). It is however impossible to make them arbitrariety smaller without limit; in electron tubes there will always remain fluctuations which are found to be connected with the distribution of velocities among the emitted electrons.

Theory of the thermal fluctuations

We have seen in the introduction that the thermal fluctuations of electricity have their source in the chaotic movement of electrons among the atoms. It may therefore be expected that those elements of an electric system will serve as origin of these fluctuations, in which electrons and atoms can exchange energy among themselves, that is, in electric resistances.

The external effect of these fluctuations may be considered to be caused by an EMF V in series with each resistance. It is easy to understand *that: this electromotive force is independent of the nature of the resistance.* Consider a resistance R connected with any arbitrary system Z (*fig. 1*), the whole in temperature equilibrium at the temperature T. The EMF of the thermal fluctuation, which we imagine to be in series with R, causes a certain current to flow through the circuit, whereby a certain energy is dissipated in Z. According to the principle of detailed equilibrium, due to fluctuations in Z, an equally large amount of energy must be supplied to R. This latter energy will not change if we choose resistances of different kinds one after another instead of R; conversely therefore all these resistances must give equally large energy fluctuations.

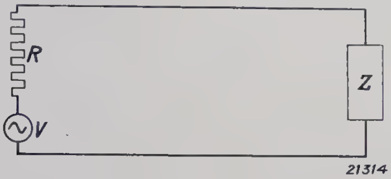

Fig. 1. The potential and current fluctuations which occur in an electric network due to the thermal motion of the electricity in a resistance R, may be considered to be caused by an alternating voltage V in series with the resistance. V is independent of the impedance Z which joins the ends of R, and is proportional to R and to the temperature.

It may further easily be deduced that the mean square of the alternating potential which is generated at the extremities of a resistance is proportional to R. If one considers a resistance R in a given circuit divided into n equal parts R_l connected in series, each resistance R_l is subject to the same conditions. The fluctuation EMF's V_l which may be considered to be in series with each R_l must therefore be equal. Together they must be equal to the alternating potential of the total resistance V. Since the potentials V_l are entirely independent of each other, and therefore $\overline{V_1 V_2} = 0$, $\overline{V_1 V_3} = 0$ etc. the mean square $\overline{V^2}$ of the sum is equal to the sum of the mean squares $\overline{V_1^2} + \overline{V_2^2} + \dots$ so that

$$n\,\overline{V_l^2} = \overline{V^2}$$

and therefore

$$\frac{\overline{V_l^2}}{\overline{V^2}} = \frac{1}{n} = \frac{R_l}{R}\,.$$

Finally we desire to know how the alternating potentials are distributed over the various frequencies and how their magnitude depends upon the temperature. It is obvious that the spectral distribution will be the same as that of the shot effect, and that the strength of the fluctuations will be given by the thermal energy kT. The result of more detailed calculations is that, independent of the impedance connected with the resistance,

$$\Delta\,\overline{V^2} = 4\,kT\,R\,\Delta\,\nu \quad . \; . \; . \; . \; . \quad (5)$$

Making use of the fact that potentials generated in a resistance by thermal causes are independant of the nature of the resistance, we propose to derive the above formula with the aid of an especially simple model. We consider as resistance a vacuum tube, to be described in more detail later. and are able by means of this imaginary experiment to show a relation between the thermal fluctuations and the shot effect. Considering the fact that we have already discussed the theory of the shot effect above, we may be permitted to use the results there obtained in the consideration of the thermal fluctuations.

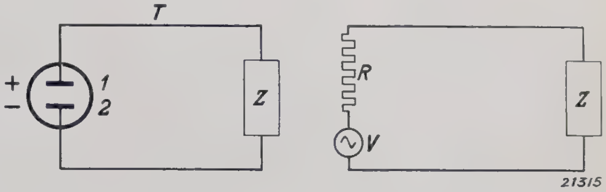

Fig. 2. A vacuum tube both of whose plates have the same temperature T (left) represents a very simple model of an ohmic resistance (right). From this model it is found that the thermal fluctuations can appear in a diode in the form of the shot effect.

Consider for instance a vacuum tube (*fig. 2*) with two similar electrodes *1* and *2* in the form of plates of the same metal which are kept at a temperature T sufficiently high to cause an appreciable emission of electrons in the electrodes. This tube behaves as a resistance: if the electrodes are joined with the poles of an EMF V, a very definite current I will flow through the tube. By definition the resistance of the tube R equals dV/dI. How large is dV/dI? Electrons leave each electrode with various velocities; as is known, they have the Maxwellian distribution of velocities corresponding to the temperature T. The (temporary) presence of electrons between the electrodes produces there a space charge which causes a minimum of potential. For the sake of simplicity we shall assume that the current density and separation of the electrodes are so small that the depth of the potential minimum which occurs is small enough in comparison with the average emission velocity of the electrons so that we may neglect its influence. In that case the average currents $\overline{I_1}$ and $\overline{I_2}$ in each direction depend only upon the emission from each electrode $\overline{I_{01}}$ an $\overline{I_{02}}$, respectively, and upon the potential difference V_a between the two plates. If the electrodes are shortcircuited externally the potential difference is zero, all the electrons emitted reach the opposite plate, and since the emissions are the same, the average current through the circuit is $\overline{I} = \overline{I_2} - \overline{I_1} = 0$. If by connection in series with a resistanceless battery V_a one plate, for instance plate *1*, is made positive with respect to the other, then the average number of electrons which pass from *2* to *1* per unit of time will remain the same, namely equal to the emission from *2* $(\overline{I_2} = \overline{I_{02}})$. The number which passes from *1* to *2* is smaller on the average since part of the electrons do not have sufficient speed to overcome the potential difference: $\overline{I_1} < \overline{I_{01}}$. The way in which this current depends upon the counter potential is given by the known starting function

$$\overline{I_1} = \overline{I_{01}}\;\varepsilon^{-eV/kT}.$$

For the differential resistance R of the tube we therefore find:

$$R = \frac{dV}{dI} = \frac{dV}{d(\overline{I_2} - \overline{I_1})} = -\frac{dV}{d\overline{I_1}} = -\frac{1}{d\overline{I_1}/dV} = \frac{kT}{e\,\overline{I_1}}\,. \quad (6)$$

The electrons are emitted independently from each electrode; for the case when the diode is short-circuited externally all the electrons always pass over, and the fluctuations of the current in each direction may immediately be calculated with the help of formula (4) for the shot effect.

Thus we find

$$\Delta\,\overline{(I_1 - \bar{I}_1)^2} = 2\,e\,\bar{I}_1\,\Delta\,\nu.$$

The fluctuations of I_1 and I_2 are not correlated; the mean square of the fluctuations of the total current is therefore exactly twice as much

$$\Delta\,\overline{I^2} = 4\,e\,\bar{I}_1\,\Delta\,\nu \quad . \; . \; . \; . \; . \; . \; . \; . \quad (7)$$

From (6) it now follows that we may substitute $e\bar{I}_1 = kT/R$ so that (7) takes the form

$$\Delta\,\overline{I^2} = \frac{4\,kT}{R}\,\Delta\,\nu \quad . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

In order to cause the same current fluctuations an EMF V in series with the diode must satisfy the equation

$$\Delta\,\overline{V^2} = \frac{4\,kT}{R}\,\Delta\,\nu\cdot R^2 = 4\,kT\,R\,\Delta\,\nu \quad . \; . \; . \quad (5)$$

It can be proved that equation (5) also holds when the resistance under consideration is not short-circuited, but connected with a system having any arbitrary impedance.

If one has a circuit arrangement in which a number of resistances occur, one may thus calculate the fluctuations of the potential occurring between two given points A and B of the circuit simply according to the laws of Kirchhoff, if one imagines a fluctuation EMF introduced in series with each resistance, the value of the EMF being given by equation (5).

Since the various EMF's exhibit no correlation, the mean square of the total potential is equal to the sum of the mean squares of the contribution of each resistance.

Thermal fluctuations in potential are unavoidable; their proportionality to the temperature suggests however a method of making them as small as possible for a given circuit: namely by cooling the elements in which the fluctuations have their source.

Finally it must be noted that just as the shot effect cannot lead to infinitely large fluctuations, an ohmic resistance cannot have an infinitely large fluctuation potential, as would follow from (5) for an infinitely wide frequency range. Just as in a saturated diode, in an ohmic resistance finite times of displacement for the electrons will play a part, so that at very high frequencies (10^{14} c/s) the variations in electricity generated will decrease with the frequency.

Order of magnitude of the shot effect and thermal fluctuation

We have already noted that the formula for the thermal fluctuations exhibits much analogy with that for the shot effect. The agreement becomes still closer when in the shot effect one does not consider the fluctuating current, but the potential V which causes the curent in a resistance R: then for the shot effect one obtains

$$\Delta\,\overline{V^2} = (2\,e\bar{V})\,R\,\Delta\,\nu,$$

and for thermal fluctuations

$$\Delta\,\overline{V^2} = (4\,kT)\,R\,\Delta\,\nu\,.$$

In the first case the potential energy $e\,\bar{V}$ per electron appears, in the second the thermal energy per degree of freedom. The numerical factors have the same magnitude when for example $T = 300$ °K (room temperature) and $\bar{V} = 0.05$ volt. For $R = 10^5$ ohms this latter amounts to a current of only 0.5 μA. The mean square of the potential for a frequency band $\Delta\nu$ of 10^4 s/c is then more than 16 $(\mu V)^2$.

Experimental testing of the results

The testing of equations (4) and (5) comes down to this: the fluctuations are amplified and the amplified current is conducted through an instrument whose indication U is a measure of the mean square of the current, for example a combination of thermocouple and galvanometer. By comparison of the result with the theoretically calculated value the physical constants e and k can be determined. In *figs. 3* and *4* are represented schematically the arrangements for the measurement of thermal fluctuations and shot effect respectively. The amplification γ_ν, further defined under the figures, may be any arbitrary function of the frequency, but must for each frequency be independent of the amplitude. It is permissible to apply the syperheterodyne principle any number of times so that a signal of frequency e can lead to a current of frequency $(\nu - p)$ at the output terminal of the amplifier.

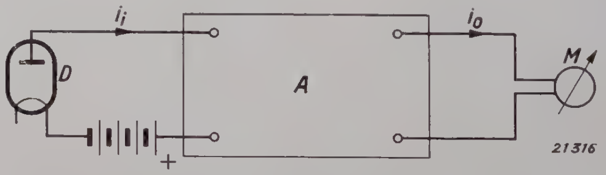

Fig. 3. Arrangement for the determination of the charge on an electron. D saturated diode (the anode current is determined by the cathode temperature). A amplifier. M instrument for measuring the mean square of the amplified current. A sinusoidal input alternating current i_i of frequency ν leads to a sinusoidal output alternating current i_o, the amplification γ_ν is i_o/i. γ_ν must be 0 when $\nu = 0$ since the direct current from the diode may not be amplified. The reading U_0 of the ammeter M caused by other sources of fluctuation besides D observed by cooling the cathode of D.

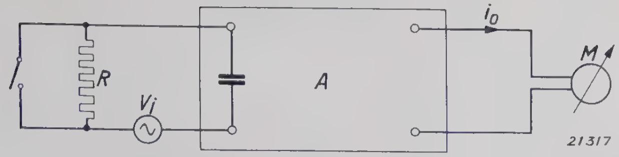

Fig. 4. Arrangement for the determination of the Boltzmann constant k. The resistance R which is the source of the thermal fluctuations to be measured is here shunted through the input capacity of the amplifier A. M is a measuring instrument for measuring the output current. A sinusoidal input alternating potential V_i of frequency ν leads to a sinusoidal output alternating current i_o: the amplification γ_ν is i_o/V_i. The reading U_0 of the measuring instrument M caused by other sources of fluctuation than R is observed by short-circuiting R, whereby care must be taken that γ remains unaltered.

In the setup for the measurement of thermal fluctuations (fig. 4) a potential V_i with a frequency ν gives a current i_o such that

$$i_o^2 = V_i^2 \gamma_\nu^2.$$

If we take for V_i the alternating potential which is generated by the thermal motion in a frequency interval $\Delta\nu$ in the neighbourhood of ν, then

$$\overline{V_i^2} = 4\,kT\,R\,\Delta\,\nu,$$

so that the contribution to the mean square of the output current is

$$\Delta\,\overline{I^2_{out}} = 4\,kT\,R\,\gamma_\nu^2\,\Delta\,\nu.$$

The total contribution of the thermal fluctuations we obtain by the summation of the above result over all the frequency intervals $\Delta\,\nu$, thus

$$\overline{I^2_{out}} = 4\,kT\,R \int_0^\infty \gamma_\nu^2\,d\,\nu.$$

If we indicate the contributions of all possible other (entirely independent) sources of fluctuation (for instance other resistances or tubes than the one under consideration) by U_0, then

$$U - U_0 = 4\,kT\,R \int_0^\infty \gamma_\nu^2\,d\,\nu.$$

In exactly the same way one finds from the setup for the shot effect

$$U - U_0 = 2\,e\,\overline{I} \int_0^\infty \gamma_\nu^2\,d\,\nu.$$

For a given arrangement the amplification γ_ν for each frequency is easily determined experimentally; the integration can readily be carried out graphically.

The constants e and k have been determined in a similar way by various investigators. In this laboratory also, accurate experiments were carried out several years ago. The result is uniformly satisfactory, since the deviations remain within the per cent maximum permissible error of measurement. It may be seen from this that it is possible in either a diode or a resistances to avoid all sources of fluctuations except those which are necessarily present for fundamental reasons; namely, the thermal effect and shot effect. One must, however, always take into consideration the phenomena discussed, and the formulae derived are of application to all branches of radio technique.

PUBLIC LIGHTING. PRINCIPLES OF STREET ILLUMINATION

by G. B. VAN DE WERFHORST.

In a previous article 1) we noted how the influence which the total outdoor illumination exerts on the public lighting differs so much inside the built-up areas from that outside the built-up areas that the subject must be divided into two parts. While in the article mentioned the lighting of the highways outside the built-up area was discussed, we should now like to discuss the public illumination installed within the built-up area, and combine the two under the term "street lighting", under which, therefore, not only the lighting of streets in the narrower sense but also the lighting of squares, boulevards, main traffic thoroughfares and the like will be understood.

In treating this subject we shall take the case of a large city. We may then leave it to the reader to apply the general principles which we discover to the case of a smaller city and to that of a large or a small town.

The large city presents all forms of outdoor illumination: lighting of the roadway itself and of its surroundings, signals, advertising illumination and private illumination. The first two in the public interest, the last two for private interests. The public lighting of a large city is certainly installed for the benefit of the public. But in this case it is not so simple as for the highways through the country to determine what the interest of the public is. The large city exhibits within its limits much variation. One is forced to make a distinction among different streets. In *fig. 1* we have drawn a schematic representation of the streetplan of a large city. While the outermost circle indicates the limits of the urban district (the built-up area), the actual centre of the city lies within the inner circle. The main thoroughfares A_1B_2, A_2B_2 etc. lead to this centre as continuations of the intercommunal highways *1, 2, 3* ... These main thoroughfares are often connected with each other by ring highways R_1, R_2. Between these latter are the residential districts and the factory districts, the better residential districts (W) are usually built out toward the west, southwest and south, the factories and working men's houses (J) toward the east, northeast and north.

The public lighting, wherever it is introduced in this total complex of streets and squares, has as one of its subjects the promotion of safety by the creation of a certain degree of visibility. We are involuntarily inclined tot hink here exclusively of traffic safety, influenced as we are by the development of modern traffic. Such onesidedness however, would lead us to a false standard. The original object of public lighting was, namely, to provide safety against hold-up and burglary by the criminal elements; we shall call this the public safety. In most of the streets of the residental sections, and in the smaller streets of the centre of the city, the street lighting has more this object of public safety than that of traffic safety.

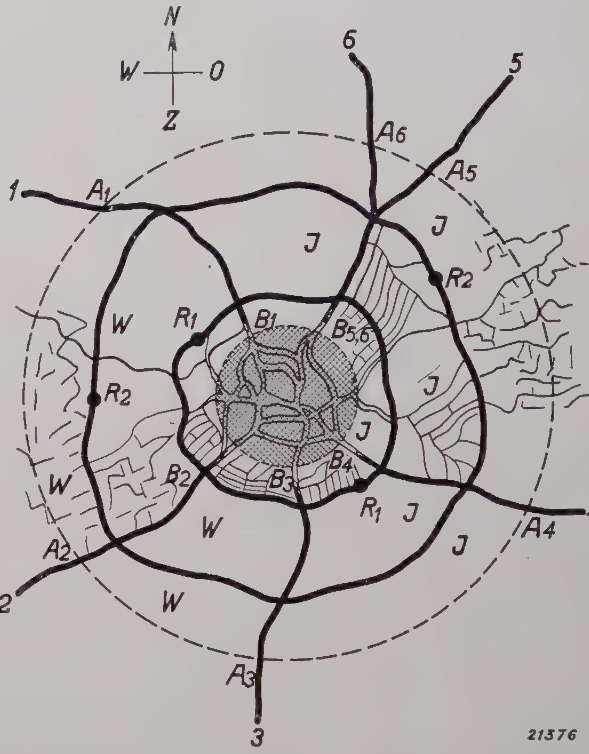

Fig. 1.

Next to safety, the appearance of the city is of importance. Especially in the centre one wants to see the fronts of the buildings in the evening also. In this part of the city, which is usually the oldest and most characteristic, these buildings give a special character to each street in the daytime. One would like to preserve this street scene in the evening, be it in an altered form. The majority of the streets in the centre of the city are furthermore shopping streets. The modern brightly lighted show-windows are an important con-

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1) Philips techn. Rev. 2, 110, 1937.

tributing factor in the street lighting, however only until ten or eleven o'clock in the evening, when the lights in most show-windows are extinguished. Because of the traffic intensity, which just then increases again due to the emptying of theatres and cinemas, the street lighting left to itself must have sufficient capacity. Such conditions will be found on most of the main thoroughfares and they will increase in degree from outside the city to its centre.

At their beginning (A_1, A_2 etc.) most of the main thoroughfares have the character of the rapid traffic roads through the country. The illumination of the house fronts is superfluous there. But toward the city the character is gradually changed, unless such a traffic highway is lined chiefly by factory complexes (A_4B_4), in which case the character of highway dominates into the centre of the city. This is even more the case with the ring highways, especially the outermost; there one may speak of a fast traffic like that on the highways through the country. These ring highways can be considered by the passing traffic as the links between intercommunal roads. For the passage of this through traffic it is favourable to have the lighting of the outermost ring highway of the same character as that of the connecting highways. On this ring highway, just as on the highways outside the city, the illumination of the surroundings is of no practical importance.

In the residential sections, especially in those with open building (garden village building, among others), the lighting of the surroundings is howe ververy important once more. From the street one must be able to distinguish sufficiently the houses behind their gardens, in the first place to orient oneself, and also for the sake of public safety. There is no question here of intense fast traffic.

While for the large intercommunal traffic highway we may fail to consider the pedestrian, he is very important in the case of all city streets, although not everywhere in the same way. In the centre of the city the shopping streets are to a great extent promenades, particularly in the evening hours. The pedestrian here is not a sort of traffic obstacle, he himself represents a very important traffic. The pedestrian wants to see and to be seen. not from considerations of safety, but because he considers it a pleasure. Here the general function of street lighting may be very well described as "for the pleasure of the road user", to use the words of our previous article in which we classified these general functions. In the residential sections however the lighting must provide the walker chiefly with public safety and the possibility of orientation.

On the main traffic thoroughfares and the ring highways the requirement of traffic safety dominates so far as the pedestrian is concerned.

While it may be seen from the above how diversified are the demands which are made on street lighting, in different streets, the problem shows still many more sides, when one considers the influence on the street lighting in a city exerted by the other outdoor illumination, and how varied this outdoor illumination is. In order to take this into account in the proper way, it must first be stated that from economic considerations a much higher level of illumination may be applied in the important streets of the centre of the city than in the unimportant streets of the residential districts, and further that in the centre of the city, for most of the streets, there is present an illuminated vertical limiting surface (the lighted fronts and show-windows), while in the residential districts, besides the so much less intensely illumined road surface, there is practically no question of a vertical lighted background. The road user is therefore in these two extreme cases (the other streets usually show transition states between these two) presented with entirely different degrees of brightness and therefore to very different sensitivity for glare.

Of the total illumination there are first the signal lights, which contribute to the public interest. Of these the traffic signal proper gives the least difficulty. It is however another question with the signals of the traffic island. Lying as they do in the average line of vision of the road user, they may be of considerable intensity in the centre of the city without being blinding, since the total brightness of the surroundings permits a fairly great intensity of these signals. The same traffic island signal in the suburban districts, however, has often a blinding effect in the much darker surroundings and thereby cancels to a large degree the effect of an otherwise adequate street lighting.

This is even more the case with the signal lights on vehicles. Since driving with "blinding lights" is usually forbidden by law within the built-up area, and this means in other words that the vehicle itself may not provide for the illumination of the way, the other lights carried by the vehicle may only be signal lights (serving to be seen and not to allow the driver to see). This signal lighting may also not be glaring. Even the "parking lamps" of many autos do not satisfy this condition and have

	1	2	3	4
Factors to be considered Type of street	Colour of the light	Level of illumination	Background and fronts of buildings	Visual brightness of light-source (lante
Promenades and boulevards in the centre of the city	1) White or corrected to appear white for pedestrians	2) Very high	3) Continuous background of illuminated building fronts	4) May be rat high due to and *(3)*
Smaller sidestreets in the centre of the city	11) White or corrected to appear white in order to correspond with *(1)*	12) Medium	13) Continuous background of illuminated building fronts	14) Must be k rather low
Main thoroughfares from the limit of the built-up area to the innermost ring highway	21) Correspond to the colour used on the highways outside the built-up areas because of *(25)* and *(26)*, no aesthetic considerations	22) Medium	23) Little background	24) Light-source must be invi ble
Main thoroughfares from the ring highway to the centre of the city	31) Gradual transition from *(21)* to *(1)*	32) High	33) Transition from *(23)* to *(3)*	34) Transition *(24)* to *(4)*
Ring highway, outermost	41) No aesthetic considerations, for *(45)* and *(46)* most suitable kind of light to be chosen	42) Medium	43) No background	44) Light-source must be inv ble *(43)* (4 *(46)*
Ring highway, innermost	51) Partial correction toward white	52) High	53) In some cases fronts which must be illuminated. Sometimes no background, gardens, park	54) When borde by buildings rather low. When borde by gardens source invisi
Main thoroughfares through factory complexes	61) No aesthetic considerations, *(65)* and *(66)* determine the kind of light	62) High	63) No background: fronts of factory buildings are too dark	64) Light-source invisible beca of *(65)* and (
Residential streets with continuous blocks of houses	71) White or corrected toward white because of pedestrians	72) Low	73) House fronts which may be dark	74) Light-source invisible beca of *(72)* and (
Residential streets with separate houses	81) White or corrected toward white because of pedestrians	82) Low	83) No background	84) Light-source invisible beca of *(82)* and (
Main thoroughfares through the residential districts	91) Rapid traffic the chief concern, therefore only slight corrections toward white for the benefit of pedestrians	92) Medium	93) No background	94) Light-source invisible beca of *(92)* *(93)* ((96)
	By white light is meant the light of the ordinary sources of light having a continuous spectrum: glowlamp, gas light, arc light. The "correction toward white" of light which is not white from gas discharge lamps means either the application of light mixtures or transformation by means of fluorescence.	Under "medium" level of illumination is meant the level of illum. of the well-lighted highways through the country, for which one must calculate the light-sources to give about 200 lumens per metre length of road, from which follows meaning of low, high and very high.	By "little background" or "no background" is meant that the background is dim with no specification of whether it is the dark sky, vague groups of trees etc.	Visible means here vi within the angle α (fi which for practical poses is considered al 15°. As visual bright only the brightness within the angle meant

5	6	7	8	9	10
Type of safety desired	Type of traffic	Visibility	Speed of observation	Contrast	Glare due to street lighting
		also dependent on the various kinds of light			
) Public traffic	6) Pedestrian, slow	7) Only white light to be considered, see *(1)*	8) May be neglected because of *(2)* and *(6)*	9) Need not be considered because of *(2)*	10) Due to *(2)* and *(3)* a fairly high degree is permissible
) Public	16) Pedestr. slow	17) Of no importance	18) Of no importance	19) Need not be considered	20) Must be avoided as much as possible
) Traffic	26) Fast traffic	27) Very important, therefore kind of light which gives greatest visibility. This is possible because of *(21)*	28) Very important, therefore best kind of light because of *(21)*	29) Very important, therefore best kind of light because *(21)*	30) May not occur
) Traffic	36) Slow and fast traffic	37) Transition between *(27)* and *(7)*	38) Transition between *(28)* and *(8)*	39) Of less importance due to *(32)*	40) To be avoided as much as possible
) Traffic	46) Fast traffic	47) Very important, choose best sort of light, permissible because of *(41)*	48) Very important, choose best sort of light, permissible because of *(41)*	49) Very important, choose most favourable level of illumination	50) May not occur
) Traffic	56) Pedestrian, slow and fast traffic	57) Important but kind of light is already determined	58) Important but kind of light is already determined *(51)*	59) Need not be considered	60) To be avoided as much as possible
) Traffic	66) Slow and fast traffic	67) Important, best kind of light possible because of *(61)*	68) Important, best kind of light possible because of *(61)*	69) Level of illumination too high to take advantage of this	70) May not occur
) Public	76) Pedestr., slow	77) Of little importance	78) Of little importance	79) Need not be considered *(71)*	80) To be avoided as much as possible
) Public	86) Pedestr. slow	87) Of little importance	88) Of minor importance	89) Need not be considered *(81)*	90) May not occur
) Public & traffic	96) Pedestr. slow and fast traffic	97) Important but kind of light is already determined *(91)*	98) Important but kind of light is already determined *(91)*	99) Need not be considered	100) May not occur

We have divided traffic into 3 groups pedestrians, slow traffic with a speed up to about 12 m.p.h. under which bicycle traffic falls and fast traffic with a speed higher than about 12 m.p.h.

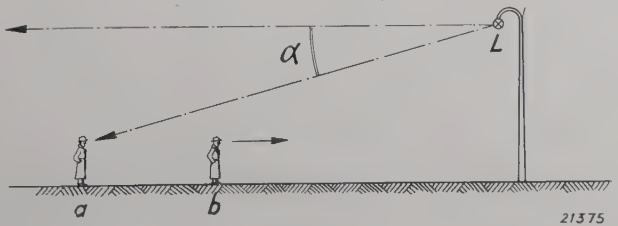

Fig. 2. Visible here means whether or not the light-source *L* is visible to the observer *a* and to all observers farther than *a* from *L*, thus within the angle *α*. Although observer *b* can see the light-source, the visibility for this observer (outside angle *α*) need not be considered.

much too great an intensity. It is, however, much worse with the signal lights of motorbusses, trams and bicycles [2]). Even in the lighted surroundings of the centre of a city, they usually have a very disturbing effect. But especially on the main thoroughfares and the ring highways every good intention of the street lighting is often made illusory by the blinding, effect of the signal of this kind of traffic.

Of still greater influence, however, is the advertising illumination.

Signal lighting (particularly the traffic signal) and street lighting — installed as they are in the interest of the public — are both in numerous cases rendered completely useless by advertising signs, which are for private benefit. The density of advertising signs can become so great, as in the heart of the greatest cities, that they begin to form a contributing factor in the lighting of the street, and even increase the level of total brightness so much that the blinding effect of all kinds of other sources of light becomes relatively less. This effect, however, remains practically confined to a very small district. Immediately outside that district the unbridled advertising signs make it senseless to ponder over what distribution of light one should apply to the street lighting, or what level of brightness is desirable for the road surface. At the present time the traffic arteries of large cities give a chaotic picture of motionless, moving and changing advertising lights, signal lights and traffic lights, with often an attempt by the street lighting to dominate all this with rows of extraordinarily strong street lamps which shine out and blind the road user [3]). The application of the law which prescribes the signal lights of the vehicles should be rigorously extended to include a prohibition against blinding by these lights also. The unbridled advertising illumination need not necessarily be limited in quantity or in extent, but it truly needs a limitation in permitted brightness depending upon its location.

Without such measures the street lighting, if it remains within economically acceptable limits, will never be able to satisfy the requirement of furnishing visibility on the road, even though the street lighting itself is carried out in the most perfect way.

The private lighting on a vehicle is, as was already mentioned, usually forbidden within the built-up areas. The private lighting, however, of factory property and emplacements along the street, of entrances, of petrol stations, of loading and unloading wharves, of playgrounds, often with festoons of coloured lights, is bound by no law. It is very often so blinding that the effect of the street lighting is very much reduced for the road user. These disturbing elements are, however, seldom to be found in the centre of the city and in the residential districts, but more along the main thoroughfares and the ring highways.

The factors which must be taken into account in the judging or projecting of the street lighting are therefore very different for the various streets.

Two other factors for which this is also the case must also be mentioned, namely the intensity and the speed of the traffic. The intensity of the traffic needs no explanation. The traffic speed, even when it is not bound by a prescribed maximum speed, is relatively low in the centre of the city, in any case so low that for the determination of the value of the street lighting proper the speed of observation, already influenced by so may other factors, may be left out of consideration. On the outermost portions of the main thoroughfares, however, on the ring highways and on the main roads through the extensive residential districts, the lighting must take into account the importance of high speed of observation with high traffic speeds.

The way in which the street lighting actually must be adapted to the various circumstances and conditions, what must be the standard for choosing among the various light sources available, in connection with colour, visibility, speed of observation, contrast [4]), how the glare [5]) must be taken into account, all these factors may be read from the summarizing table accompanying this article (page 144).

In order to make clear the use of this table let us consider a single type of street included in the table, for example the inner ring highway.

On such a street there are usually important, often impressive buildings. It is desirable to use a colour of light which does not lead to too great colour distortion of the whole (51), because the pedestrian traffic and the slow vehicle traffic (56) as road users do not relinquish all aestetic demands. Because of the importance of this street the level of lighting employed is high (52), so that the special contrast which can be obtained with certain sources of monochromatic light would in any case not be evident here (59). This consideration thus no longer holds as a loss factor in the choice of colour for the lighting (51). Since in this case account must be taken of fast traffic (56), visibility (57) and speed of observation (58) are important, but when the colour of the light has once been chosen, it is of no further importance for such a street to consider how a different kind of light might possibly increase the sharpness of vision and the speed of observation. Glare (60) is dependent not only on the source of light itself, but also on the total brightness of the surroundings, and this latter in its turn on the background. If this latter consists of the fronts of buildings (53), it is then desirable to keep them illuminated for the sake of the aspect of the street. In order to do this lamps must be used which send out light to the side and to a limited degree even vertically upwards, which again involves that the lamps shall show a certain visual brightness (54) for the road user.s This visual brightness may not be too blinding (60) but will be the less so because of the presence of a lighted background (53). If there is no background (53) then the necessity for the lighting of the fronts of the buildings is removed, but at the same time the requirement concerning glare becomes much more rigorous (54) (60).

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[2]) This last only of course for those cities where there is an intensive bicycle traffic.

[3]) London, Paris and Berlin present striking examples.

[4]) See P. J. Bouma, Philips techn. Rev. **1**, 102, 166, 1936.

[5]) See P. J. Bouma, Philips techn. Rev. **1**, 225, 1936.

The table (which might be extended to include still more types of streets) shows such a variety of problems set before those who must plan the street lighting, that it is manifestly impossible to speak of the public illumination of a large city as simply "street lighting".

Without a division of the subject — the one given here or some other — every dicussion or treatment of the subject leads to endless misunderstanding.

THE RECORDING OF RAPIDLY OCCURRING ELECTRIC PHENOMENA WITH THE AID OF THE CATHODE RAY TUBE AND THE CAMERA

by J. F. H. CUSTERS.

Summary. At different current strengths of the electron beam the maximum scanning speed for a green and a blue-fluorescing cathode ray tube was determined. The experiments carried out with various photographic material give as result that the greatest speed can be recorded by the use of a green-fluorescing screen and a suitable green-sensitive emulsion. With a tube for 2 kilovolts and a beam-current strength of 200 microamperes a scanning speed of about 1 kilometre per second was found with the use of Agfa Isochrom material. The camera lens was used at a stop of 1/4.5 and the object-image size reduction was 6 to 1.

Introduction

The cathode ray tube is a modern measuring instrument which is finding everwidening application for the most diverse uses. The phenomena which are being investigated with the help of this instrument may be divided into two categories:

1. Periodic phenomena.
2. Non-periodic phenomena.

In the case of periodic phenomena a motionless oscillogram can be obtained on the fluorescent screen of the tube with the aid of a synchronized "saw-tooth" potential, by applying the potential to be investigated to one pair of deflecting plates, and the saw tooth potential to the other pair. These potentials deflect the electron beam in two mutually perpendicular directions, whereby the form of the unknown potential appears on the screen as a function of time. The establishment of a motionless oscillogram presents no difficulties, if only the potentials vary in the same way with time during every period, so that the oscillogram really is motionless. When a camera is used one can simply expose so long that a sufficient blackening of the plate is produced. Often it will be unnecessary to photograph, and the desired values can immediately be read from the image on the screen.

In the case of non-periodic phenomena which take place only once, on the other hand, photographic recording becomes essential. Here, also, it seems obvious to let the potential appear on the screen as a function of time, by applying to the other pair of deflecting plates a potential increasing linearly with the time. This deflecting voltage does not, however, need to be repeated periodically.

While with a motionless oscillogram it is not essential that the brightness of the spot should reach high values, it is of primary importance in the case of rapidly occurring non-periodic phenomena that it should do so. The brightness in this case must be so great that a sufficient blackening is obtained on the sensitive emulsion, although the image of the light spot acts on a surface element of the emulsion once only. The amount of light which falls upon such an element will therefore depend upon the speed of the spot (so-called scanning speed), while in addition still other factors such as the emulsion sensitivity and the lens aperture of the optical system, among others, play a part which we shall consider in some detail.

With these considerations in mind investigations were carried out with two definite types of cathode ray tubes having green- and blue-fluorescing screens respectively, but otherwise similarly constructed. From the experiments we could deduce the maximum value of the scanning speed. Moreover the results were given in such a form that the maximum scanning speed to be expected from other types of tubes could be fairly approximately calculated.

Derivation of the expression for the maximum scanning speed

When the light sensitive material and the camera type are given, the maximum scanning speed v_{max} for a given cathode ray tube can be calculated. By v_{max} we understand the speed of the moving spot at which is obtained a blackening of the photographic plate, giving a density $S = 0.1$ above "fog". The formula reproduced below expresses the determining factors in outline form. In *fig. 1* the following symbols are used :

Sch the fluorescent screen of the tube,

D the diameter of the light spot having the area $F = \pi/4 \cdot D^2$,

O the lens of the camera with surface O, lens diameter d and focal distance f, so that the stop is $1/L$, where $L = d/f$,
P the photographic plate, which receives the image of the spot.
D' the diameter of the image of the spot with area $F' = \pi/4 \cdot D'^2$,
b the image distance.

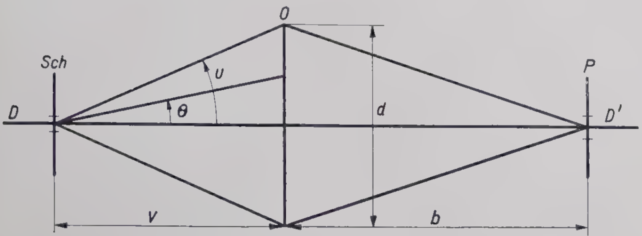

Fig. 1. Image of the fluorescent screen *Sch* formed by the lens O of the camera on the light sensitive plate P. The light spot of diameter D is reproduced in the image with diameter D'.

Let the brightness of the light spot be B. Under the condition which is well fulfilled by ordinary fluorescent screens, that the spot radiates according to Lambert's cosine law, B is independent of the direction.

The blackening of an element of the photographic plate is determined by the amount of light which strikes the element, which in its turn is determined by the product of the intensity of the illumination E and the exposure time t. The intensity of the illumination E is connected with the brightness B in the following way:

$$E = a\,B \cdot \frac{O}{b^2} \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

Due to reflection and absorption not all the light falling upon the lens will pass through it, but only a part which is accounted for by the factor a 1).

If we introduce the enlargement N by writing $b = (N + 1)\,f$, the expression becomes

$$E = a \cdot \frac{\pi}{4} \cdot B \cdot \frac{L^2}{(N+1)^2} \quad . \; . \; . \; . \quad (2)$$

The exposure time is found as follows. In *fig. 2* let p be the emulsion element over which the centre of the moving spot moves along the line $L\,L'$, so that when we indicate the speed of the image by v_b and that of the spot by v, the following holds:

$$t = \frac{D'}{v_b} = \frac{D}{v} \quad . \; . \; . \; . \; . \; . \; . \quad (3)$$

For the amount of light we thus find:

$$Et = a \cdot \frac{\pi}{4} \cdot \frac{L^2}{(N+1)^2} \cdot \frac{BD}{v} \quad . \; . \; . \quad (4)$$

The maximum scanning speed is determined by the smallest amount of light $(Et)_{min}$ which is just sufficient to cause the already mentioned minimum blackening $S = 0.1$. From this condition it follows that

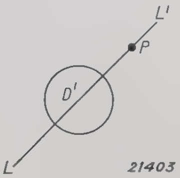

Fig. 2. The image of the spot with the diameter D' moves along the line $L\,L'$ on the light-sensitive emulsion and falls upon an element p of the emulsion during the time t.

$$v_{max} = a \cdot \frac{\pi}{4} \cdot \frac{L^2}{(N+1)^2} \cdot \frac{BD}{(Et)_{min}} \quad . \; . \; . \quad (5)$$

Let η be the light yield of the fluorescent screen in candles per watt. If we introduce in watts the energy of the electron beam and assume that η is independent of this energy, the following holds:

$$BF = V_a \cdot I_a \cdot \eta \,, \quad . \; . \; . \; . \; . \; . \quad (6)$$

where V_a is the final anode potential and I_a the current strength of the beam.

If we substitute this in the expression for v_{max}, we find:

$$v_{max} = a \cdot \frac{L^2}{(N+1)^2} \cdot \frac{V_a I_a}{D} \cdot \frac{\eta}{(Et)_{min}} \text{ km per sec} \quad (7)$$

when D is expressed in mm.

Under given circumstances almost all the factors in the above expression are known, among them the diameter of the spot and the candle power per watt. $(Et)_{min}$ is not known. None of the various methods of indicating the sensitivity of a photographic emulsion, such as the Hurter and Driffield number, °Scheiner or °DIN, makes it possible for us to calculate $(Et)_{min}$. All the methods mentioned are based upon sources of more or less white light, while cathode ray tubes emit blue or green light limited to a fairly narrow region of the spectrum, as may be seen from *fig. 3*.

An emulsion sensitive only in the blue will have a certain sensitivity expressed in any of the ways

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1) In the above expression for the intensity E of the illumination the substitution of $b = f$ (for infinite distance) transforms it into the well-known formula

$$E = aB \cdot \frac{\pi}{4} \cdot \frac{d^2}{f^2} = a \cdot \frac{\pi}{4}\, B\, L^2 \,.$$

mentioned, while it will be extremely small in green fluorescence light. Therefore for $(Et)_{min}$ we write simply $1/\beta$, a constant factor which depends upon the spectral distribution of the energy of the fluorescence light and upon the spectral sensitivity of the emulsion. For each emulsion in combination with a given fluorescent screen β must be determined experimentally. For v_{max} we finally obtain:

$$v_{max} = a \cdot \frac{L^2}{(N+1)^2} \cdot \frac{V_a I_a}{D} \cdot \eta \cdot \beta \quad . \; . \; . \; . \quad (8)$$

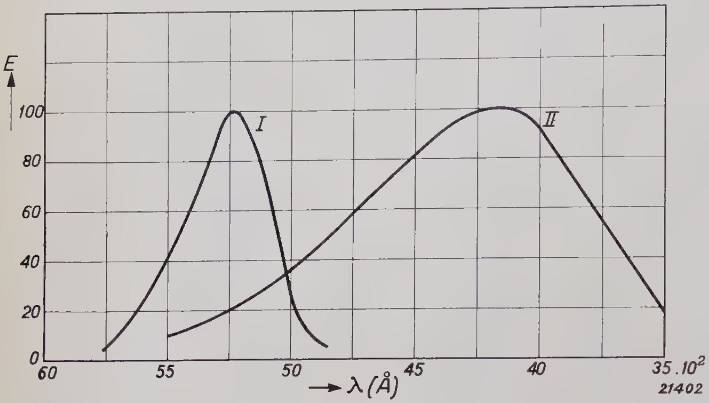

Fig. 3. Curves representing the relative energy in the spectrum of the light spot as a function of the wavelength.
Curve *I* is for the green-fluorescing screen.
Curve *II* is for the blue-fluorescing screen.

We will discuss first the results of the measurements of the maximum scanning, and then later and in more detail study the different variables which appear in the above expression.

Experimental determination of the maximum scanning speed

For a tube with a green-fluorescing screen (Philips DG 16 - 2) and one with a blue- fluorescing screen (Philips DB 16 - 1) the blackening of the recorded oscillogram was studied in its relation to the writing speed. The diameter of the screens of these tubes is 16 cm, the maximum potential of the final anode 2 kV. A camera was used with $L = 1/4.5$ and $f = 10.5$ cm. A reduction in size of six times was used in every case. The light sensitive material was the Agfa Isochrom Plate.

The phenomenon which took place on the screen was sinusoidal vibration passing once across the screen. With the aid of a circuit arrangement especially designed for the purpose it was possible to apply the required beam-current and to determine the velocity of the linear motion of the spot, and finally not only the frequency but also the amplitude of the sinusoidal alternating potential could be regulated.

In *fig. 4* one of the photographs is reproduced. The given scanning speed applies to those parts of the curve where the spot passes through the equilibrium position of the sinusoidal vibration. It is expressed as follows in terms of the wavelength λ of the sinusoidal curve, the frequency ν of the vibration and the amplitude A:

$$v = \nu \sqrt{\lambda^2 + 4\,\pi^2 A^2} \quad . \; . \; . \; . \; . \quad (9)$$

Care was taken in every case that λ^2 was sufficiently small with respect to $4\pi^2 A^2$ to be neglected, so that

$$v = 2\,\pi\,\nu\,A \quad . \; . \; . \; . \; . \; . \quad (10)$$

The amplitude $A/6$ was measured on the photographs, while ν was read off on a calibrated tone generator.

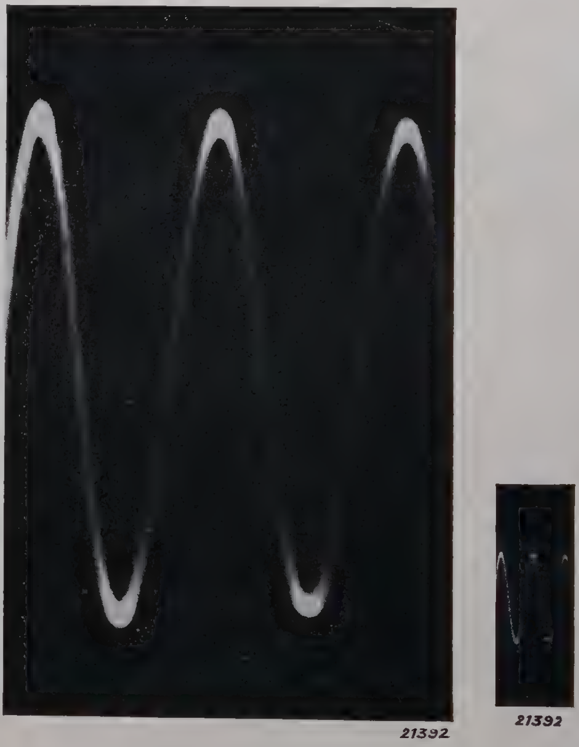

Fig. 4. Photograph of a sinusoidal vibration passing once over the green-fluorescing screen. The frequency was 4000 c/s, the beam-current 193 microamperes, while the speed at the points where the vibrating spot passed through the equilibrium position was 850 m/sec. The reduction in size of the photograph was 6 times. The small figure is a direct copy of the original photograph, while the other figure is a sixfold enlargement from the negative.

The blackening at the above-mentioned equilibrium positions of the sine curve was measured with the help of a Moll microphotometer. In *fig. 5a*, for the blue-fluorescing screen, the blackening S

is plotted for three different current values. At low speeds the blackening increases rapidly with decreasing speed, while on the other hand it decreases very slowly with increasing speed in the interesting region of high speeds.

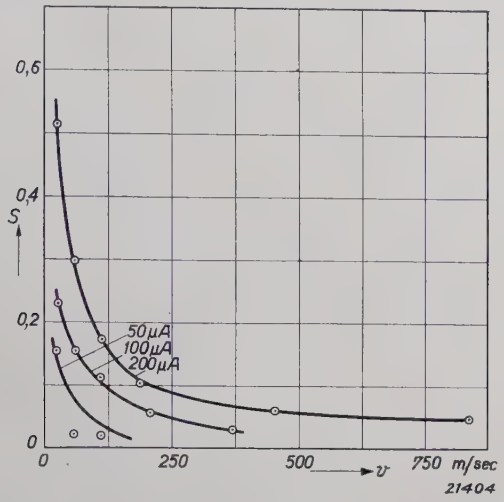

Fig. 5a. The blackening in those points of the recorded sine curve where the vibrating spot passes the equilibrium position is plotted against the scanning verlocity v of the spot with the beam-current strength as parameter. Blue-fluorescing screen.

The curves of this figure are actually only characteristic curves for the light sensitive material, but plotted in a special way. For the amount of light striking an element we found the expression:

$$Et = a \cdot \frac{\pi}{4} \cdot \frac{L^2}{(N+1)^2} \cdot \frac{BD}{v} \quad . \quad . \quad . \quad (4)$$

With the condition that D with a given I_a is, in the first approximation, independent of v (which condition is fairly well fulfilled, when v is not too small), and since with I_a constant the brightness B is also constant, we obtain

$$Et = \text{const} \cdot \frac{1}{v} \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

If we plot the blackening as a function of $\log Et = \log \frac{\text{const.}}{v}$, we expect to obtain a blackening curve. In fig. 5*b* the blackening is plotted in relation to log 1/*v*; the curves plainly show the well-known form of the characteristic of photographic emulsions. The slow decrease with increasing speed in the regions of high speeds results from the curved shape of the beginning of the blackening curves and it follows that even with large changes in the scanning speed in this region the blackening changes but little.

From the curves of fig. 5a, at $S = 0.1$, we may immediately read off the maximum scanning speed, which corresponds to the various beam-current values. These values are collected in *Table I.*

The corresponding measurements for the green-fluorescing screen are shown in *figs. 6a* and *6b*, while in *table II* the maximum scanning speeds corresponding to different current strengths are given. The region investigated in this case was more extensive, with regard to v as well as to I_a. From fig. 6*b* it appears even more clearly than from fig. 5*b* that we were determining nothing else but the characteristic curves of the light sensitive emulsion upon illumination with fluorescence light; the curves belonging to various values of I_a can be made to coincide with each other by a displacement of the zero point of the log 1/*v* axis.

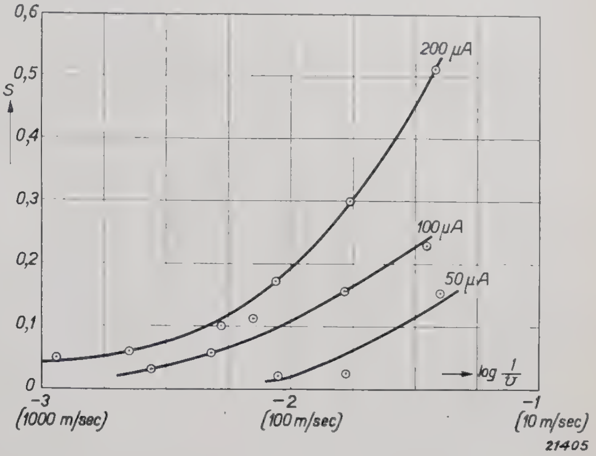

Fig. 5b. The blackening in the equilibrium points of the recorded sine curve is plotted as a function of log 1/*v* with I_a as parameter. The curves show the form of the well-known characteristic curve of a photographic emulsion. Blue-fluorescing screen.

A glance at both tables is sufficient to show that with Agfa Isochrom as light-sensitive material the green-fluorescing screen is far better than the blue-fluorescing one, when it is a question of recording rapidly occurring phenomena.

Is Agfa Isochrom much more light-sensitive in the green than in the blue? On the contrary, at 535 mμ the sensitivity of this emulsion is only just over 40 % of that at 400 mμ [2]). The energy sent out in the form of green light by the green-fluorescing screen is thus considerably more than the energy emitted by the blue-fluorescing screen in the form of blue light, when the electron beam has the same energy. A discussion is given below of several other emulsions investigated.

Consideration of the variables in the expression for the maximum scanning speed

Now that v_{max} is determined experimentally we propose to study the different variables in expression (8) for v_{max}.

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[2]) M. Biltz, Agfa-Veröff. Bd. IV, p. 32. Leipzig 1935.

Table I.

Blue-fluorescing screen (Tube DB 16-1)

Beam-current strength in microamperes	Maximum scanning speed in metres per second
50	50
100	115
200	210

Stop 1/4.5
Reduction in size 6 times
Agfa Isochrom

The value at 50 μA is rather uncertain, since the number of points on the curve is so small.

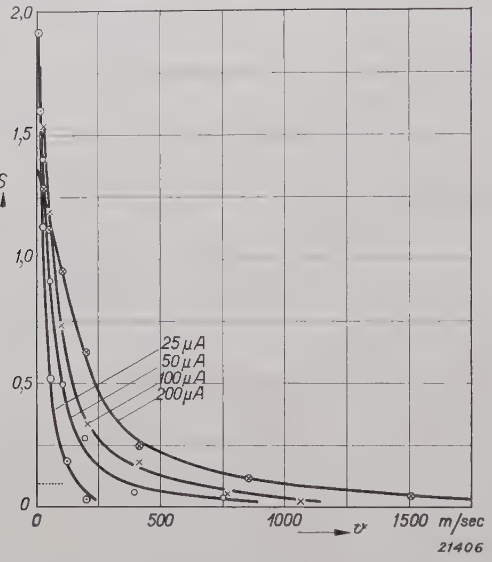

Fig. 6*a*. The blackening in those points of the recorded sine curve where the vibrating spot passes through the equilibrium position is plotted against the scanning speed v of the spot with the beam current I_a as parameter. Green-fluorescing screen.

Table II.

Green-fluorescing screen (Tube DB 16-2)

Beam-current strength in microamperes	Maximum scanning velocity in meters per second
25	165
50	360
100	615
200	990

Stop 1/4.5
Reduction in size 6 times
Agfa Isochrom

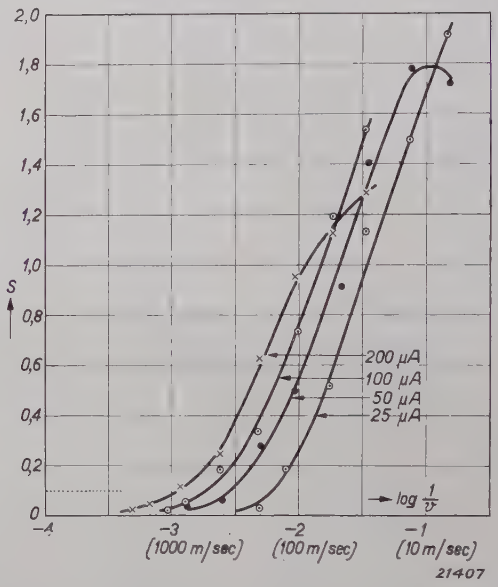

Fig. 6*b*. The blackening in the quilibrium points of the recorded sine curve is plotted as a function of log $1/v$ with I_a as parameter. The curves show the form of the well-known characteristic curve of a photographic emulsion.
Green-fluorescing screen.

Some of the curves begin to deviate very much in the region of low velocities (10—100 m/sec) from the straight part of the blackening curve. This is not the well-known bending of the curve at greater densities, but is caused by the local electric charging of the fluorescent screen at low scanning speeds, whereby the light spot does not become more intense, but much larger.

a, L and N are determined by the camera. The coefficient a will differ from one lens to another; moreover it depends, although to a slight degree, upon the wavelength. In general a will be somewhat smaller for blue light than for green light. With objectives of simple construction a may be set approximately equal to 3/4. We investigated a at $\lambda = 5461$ Å and 4358 Å by allowing a very narrow beam of light to pass through the lens in the direction of the axis and we found $a = 0.72$ and 0.705 respectively.

The stop of the widest aperture lenses is approximately 1/2.

We shall dwell at greater length upon the enlargement N. In *fig. 7* v_{max} is plotted as a function of N, while all the other factors in the expression are kept constant and $v_{max} = 1$, when $N = 1$. We see from this curve that v_{max} increases with decreasing N, that is to say, according as the reduction in size is greater. When $N = 1/8$ for instance, one may record phenomena which occur 3.16 times as rapidly as when $N = 1$, for the same plate blackening. Too great a reduction, however, serves no useful purpose, since the gain in speed is small from the point $N = 1/10$, and since the recorded oscillogram becomes more difficult to read.

Let us now consider $V_a I_a / D$. At the beginning we may keep I_a constant and see how $V_a D$ varies with V_a. It is known that with increasing potential V_a on the final anode the diameter D also increases, but less than V_a, so that in order to reach a large value of v_{max} one must take the maximum value for V_a which is permissible with a given type of tube. Thus if we maintain V_a constant at this value v_{max} still depends upon I_a/D.

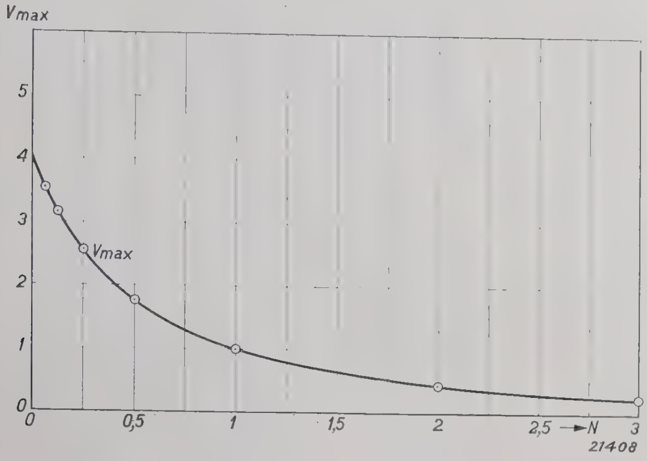

Fig. 7. Maximum scanning speed v_{max} as a function of the enlargement N. When $N = 1$, v_{max} is set equal to 1.

The scanning speed v_{max} therefore appears not to be determined solely by the brightness B of the spot but depends upon the product of spotdiameter and spotbrightness. Since in connection with the resolving power of the tube a small spot diameter is required, great brightness is important. As for the dependence of I_a/D on I_a, we may note that D increases slightly with increasing I_a. We have examined this relation separately.

On the photographs which were taken, with constant V_a but varying I_a and v, the diameter of the spot D was measured at the equilibrium points of the sine curve under a visual comparator. We thereby obtained the surprising result that, especially for the greenfluorescing screen, in the region of high speeds I_a/D was found approximately constant, independent of I_a. This cannot, however be correct, since then v_{max} would be in dependent of I_a.

With high current strengths and the consequent strong blackening of the negative the error in the visually determined D will be slight, but at low current strengths the measured value can be much smaller than the true. This occurs partly, because with small illumination only a part of the spot in the centre is sensitized above the threshold value and moreover because the apparent breadth of a line estimated non photometrically is found to small as a result of the contrast.

Let us assume on the other hand that D has a constant value independent of I_a, then we find with the green-fluorescing screen the following calculated values for v_{max}, beginning with $v_{max} = 990$ m/sec, when $I_a = 200$ μA, so that the expression is now:

$$v_{max} = \frac{990}{200} \cdot I_a \; (I_a \text{ in } \mu\text{A}). \quad . \quad . \quad (13)$$

Table III.

I_a in micro-amp.	v_{max} in m/sec calculated	v_{max} in m/sec measured
25	124	165
50	248	360
100	495	615
200	990	990

From *table III* it is seen that we also may not consider the diameter of the spot as constant, although D changes only slightly with increasing I_a. The table shows us the relation between D and I_a. As we already noted the visually determined value of D is correct for high current values. It is found in the case of the green-fluorescing screen to be equal to 1.44 mm, when $I_a = 200$ μA and $v = 850$ m/sec. When $I_a = 100$ μA, D will therefore be (see Table III) $\frac{495}{615} \cdot 1.44 = 1.16$ mm, etc. In *fig. 8* the D calculated in this way is plotted as a function of I_a. With the blue-fluorescing screen we find a similar relation. We did not examine the latter in sufficient detail, however, to enable us to reproduce a curve with adequate degree of certainty.

Finally D depends upon the scanning speed v. Here again we encounter the disadvantage of visual measurement, so that in *fig. 9* we reproduce only the curve for the green-fluorescing screen at the highest current used, $I_a = 200$ μA, where the deviations from the true spot diameter are small. As might be expected D increases strongly with decreasing v. The cause of this lies in the local electric charging of the fluorescent screen. In the interesting region of high speeds D changes only very slightly with v and the calculated diameters in fig. 8 refer to this region.

As the last variable let us consider η, the light in candles per watt. It was measured with the aid of a flicker photometer. A television raster having a definite area was made on the fluorescent screen, while the speed of the spot was of the same order of magnitude as in the above-mentioned measurements of the blackening (200 m/sec). The potential of the final anode was kept constant, while the brightness of the screen was determined for different beam-currents. Within the limits of accuracy of the measurements, η was found approximately constant, namely equal to 1.2 candles per watt with the green-fluorescing screen, while with the blue-fluorescing screen η was found equal to 0.038 candles per watt. From these data we may calculate the factor β by means of the expression for v_{max}. With Agfa Isochrom as light sensitive material we find

green-fluorescing screen: $\beta = 110$, when $I_a = 200\ \mu$A, $V_a = 2095$ volts, $v = 990$ m/sec and $D = 1.44$ mm.

blue-fluorescing screen: $\beta = 735$, when $I_a = 200\ \mu$A, $V_a = 2095$ volts, $v = 210$ m/sec and $D = 1.44$ mm.

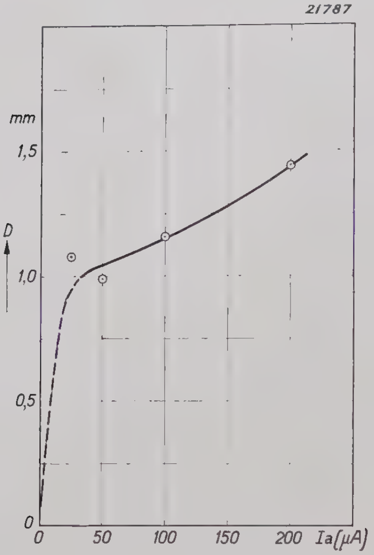

Fig. 8. Dependence of the diameter of the spot D on the beam-current I_a for the green-fluorescing screen in the region of high scanning speed.

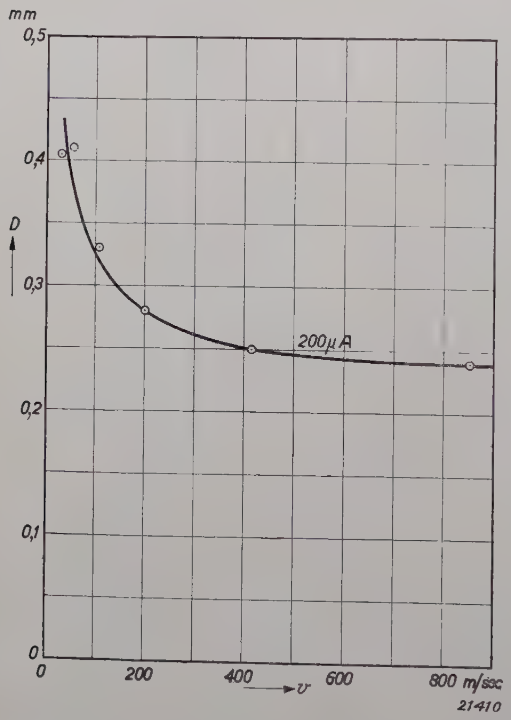

Fig. 9. Dependence of the spot diameter D on the speed of scanning v for a definite beam-current in the case of the green-fluorescing screen.

It is obvious that β is much greater with the blue-fluorescing screen than with the green-fluorescing screen, since the photographic emulsion is relatively much more sensitive in the blue region of the spectrum than the human eye.

Resolving power

It is clear that the knowledge of the maximum scanning speed does not suffice to answer the question as to which details occurring with a certain speed can still be observed in the recorded oscillogram. In this question the diameter of the spot plays a part. The resolving power of a cathode ray tube has been defined in various ways. None of these definitions is particularly lucid. The simplest way of indicating the resolving power of a tube seems to us to lie in the relation v_{max}/D, which multiplied by a constant is equal to the highest frequency which can still just be observed, as is discussed below in some detail.

On an oscillogram changes in the amplitude of the order of magnitude of the diameter of the spot can still be fairly well observed and read off. In order to discover what frequency can just be observed we refer back to the relation derived above between scanning speed, amplitude and frequency

$$v = 2\,\pi\,\nu\,A \quad . \ . \ . \ . \ . \ . \quad (10)$$

If in this equation we write $v = v_{max}$ and $A = D$, then the maximum frequency ν_{max} follows:

$$\nu_{max} = \frac{v_{max}}{2\,\pi\,D} \quad . \ . \ . \ . \ . \quad (14)$$

For the green-fluorescing screen with $v_{max} = 990$ m/sec and $D = 1.44$ mm, when $I_a = 200\ \mu$A, we find $\nu_{max} \approx 110\,000$ c/s. It is true that the above expression is not strictly valid, since it has been assumed that the wavelength is much less than $2\,\pi\,A$, nevertheless the error is restricted to 10 per cent.

Knoll[3]) attempts to indicate the resolving power in another way. He starts from a "normal oscillogram" for which the relation between amplitude and spot diameter is equal to 50, so that an accuracy of reading of 2 per cent is required, since variations of the order of the spot diameter may still be observed. Knoll now refers v_{max} as found from measurements to this normal oscillogram and introduces the "relative maximum scanning speed"

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[3]) M. Knoll, Z. techn. Phys. **12**, 54, 1931.

v_{max} (bezogene maximale Schreibgeschwindigkeit), which is defined in the following way:

$$v_{r\,max} = v_{max} \cdot \frac{1}{50} \cdot \frac{A}{D}, \quad . \; . \; . \qquad (15)$$

where A is the amplitude, D the diameter of the spot and v_{max} the experimentally determined maximum scanning speed. In the case of the green-fluorescing tube we find, when $I_a = 200$ μA, $A = 4.0$ cm, $D = 0.144$ cm and $v_{max} = 990$ m/sec (experimental data)

$$v_{r\,max} = 550 \text{ m/sec}, \quad . \; . \; . \; . \; . \qquad (16)$$

while the accuracy of reading is

$$100 \cdot \frac{D}{A} = 3.6\,\% \quad . \; . \; . \; . \; . \qquad (17)$$

Light-sensitive material

After the relation between blackening and scanning speed had been carefully examined with Agfa Isochrom as the light sensitive emulsion, several other kinds of material were studied, in order to see whether or not they also are suitable. For this purpose photographs were made on plates from various sources, in every case under the same conditions, namely with $I_a = 100$ μA and $v = 400$ m/sec with the blue-fluorescing screen and with $I_a = 100$ μA and $v = 800$ m/sec with the green-fluorescing screen. It follows from these measurements that for the green-fluorescing screen the following materials are suitable:

Gevaert Ultra Panchro [4]), Agfa Isopan ISS, Agfa Isochrom, Kodak Supersensitive Pan Film, Perutz Braunsiegel, Ilford Commercial Ortho Film, and Lumière Super S.E., while for the blue-fluorescing screen the following proved serviceable:

Gevaert Superchrom, Agfa Ultra Spezial, Lumière Extra Rapide, Perutz Braunsiegel, Ilford Iso Zenith, Mimosa Oscillographpaper and Kodak Supersensitive Pan Film.

From a comparison of the measurements carried out with the various photographic materials it appears that the green-fluorescing screen in combination with a suitable green-sensitive emulsion is considerably better than the blue-fluorescing screen in combination with the most blue-sensitive material. The blue fluorescing screen certainly offers an advantage if one works with a moving film instead of on a time basis, since this screen has only an extremely short after-glow. In most cases however one may usually work to advantage with a stationary camera, and use one of the two parts of deflecting plates for a potential varying linearly with the time.

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4) With Gevaert Ultra Panchro v_{max} (2 kV, 200 μA and DG 16-2) was found equal to 2 km/sec.

PRACTICAL APPLICATIONS OF X-RAY ANALYSIS TO THE TESTING OF MATERIALS XI.

by W. G. BURGERS.

In general the mechanical properties of a crystal are dependent upon the direction with respect to the axes of the crystal. A good example is the mica crystal which is extremely easily split along a definite crystal plane (the cleavage plane), while perpendicular to this plane it is only broken with great difficulty. Differences of this sort may, however, be found to a greater or a lesser degree with all crystals; for example, for an aluminium crystal the tensile strength in a direction along a body diagonal of the cubic crystal lattice is almost twice as great as in the direction along an edge of the cube.

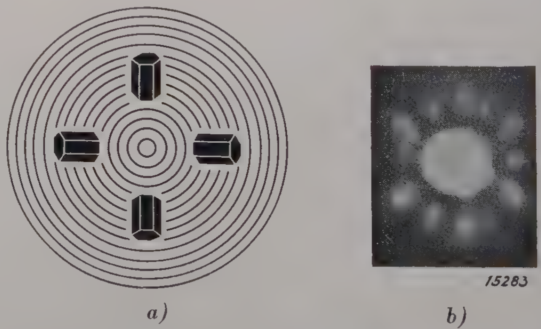
What has been stated above about the mechanical properties is also true for physical and chemical properties. Here too differences often appear when the properties are measured in different crystallographic directions. As an example we may point to the unequal resistance to attack of different crystal planes by chemical reagents, which, in the case of the etching of pieces of metal, results in the crystalline structure becoming visible.

In a crystalline material which is built up of very many small crystallites, this "anisotropy" of the properties of the crystal will be lost if the crystals lie at random as regards the position of their lattices. In that case of course all possible crystallographic directions occur in a given direction of the material, and therefore the mutual differences between these crystallographic directions are not manifested. Such a material is called "quasi-isotropic".

If however the crystallites assume definite preferential orientation as regards the position of their axes, then the anisotropy of the individual crystallites will be maintained, to a certain degree, also for the material as a whole depending upon the nature and the accuracy of the orientations. Materials which exhibit this phenomenon are said to have a "texture", which expresses the fact that the distribution of the directions of the crystal axes over the space is not uniform. Textures may occur naturally in a material or they may be induced in it by factors connected with the working or preparation.

The occurrence of a texture in a material may either be desired or even required because of a possible practical application, or it may be undesired. This depends entirely upon the nature of the practical application. In one case one may desire a material with properties as near as possible equal in all directions, in another case advantage is taken of the presence of a very pronounced anisotropy which makes the material suitable for the purpose in view. It is therefore clear that the determination of the presence or absence of a texture (and when present, of its nature) may be very important for judging the utility of a material. As we have already explained previously, this can often be deduced from the character of the interference lines on X-ray photographs. If the crystallites of a material have absolutely no preference for particular positions, then the lines are equally blackened along their entire course (either regularly or, in the presence of larger crystallites [1]), in the form of separate points). A texture on the other hand manifests itself in general in the following way. Along each interference line parts with a heavy blackening alternate with parts where the blackening is much slighter, due to the fact that in a given direction there are many more crystal planes which reflect the X-rays than in other directions. From the way in which light and dark alternate the X-ray crystallographer can moreover deduce how the crystal planes are distributed in space as regards their position, that is to say, the character of the texture present.

Examples of natural textures have already been encountered in the course of this series of articles



a) b)

Fig. 1. *a)* Diagrammatic representation of the texture of a real pearl. It consists of concentric layers of calcium carbonate. Each layer is built up of sixsided symmetrical crystals, whose axes are always perpendicular to the layers.
b) X-ray diagram of a real pearl; six-fold symmetrical pattern.

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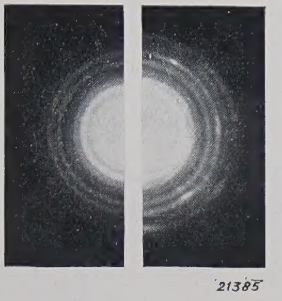
[1]) Cf. example **21**, Philips techn. Rev. **2**, 29, 1937.

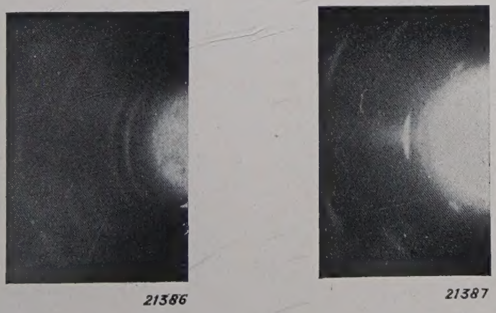
in the investigation of the genuineness of pearls [2]) (*fig. 1*), where it was shown that pearls are built up of crystallites of calcium carbonate arranged in a very definite way. In soapstone [3]) (*fig. 2*) portions were shown to occur in which the crystallites exhibit a greater or smaller preference for certain positions, a fact which has resulted in the occurrence of cracks upon heating the material. Such natural textures are the result of processes which have been active during the growth or formation of the substance considered. They are very often present, especially with substances which occur in the plant and animal kingdoms, and it may indeed be considered rather an exception when such substances are entirely anisotropic.



a) *b)*

Fig. 2. X-ray photographs of soapstone.
a) a portion which does not crack upon heating: regular distribution of the intensity along the rings indicates a quasi-isotropic material.
b) a portion where cracks appeared upon subsequent heating: interference rings with maxima and minima of intensity indicate texture.

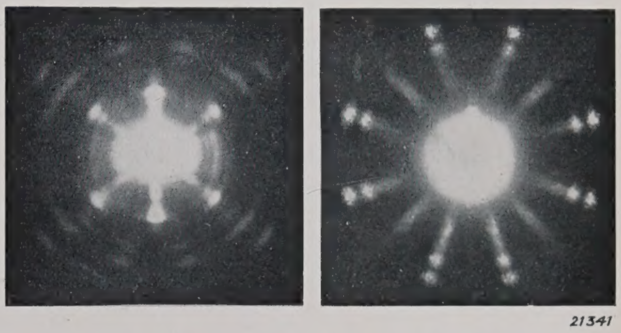
An "artificial" texture has already also been discussed, namely that of the nickel films which were deposited electrolytically on a copper rod [4]) (*fig. 3*). The occurrence of the texture was in this case probably the result of the fact that the nickel crystals grow most rapidly in a definite direction which may vary with the electrolysis conditions (composition of the bath, density of the current etc), and therefore only "favourably" oriented crystals appear on the surface of the deposited nickel film. Properties of the films such as gloss and hardness may depend upon the texture produced.



a) *b)*

Fig. 3. X-ray photographs of electrolytically deposited nickel films.
a) shiny film, shows no texture.
b) dull film, shows pronounced texture.

A second example was formed by the nickel-iron strip which is used for the construction of the cores of Pupin loading coils [5]). In this case not only the rolled, unannealed material, but also the subsequently recrystallized material exhibits a pronounced texture, as may be seen from the X-ray photographs reproduced in *fig. 4*. The texture caused by rolling is a direct result of the fact that the individual metal crystals are distorted by means of a sliding movement along definite crystallographic planes (the so-called slip planes), and these latter have a tendency to take up positions parallel to that in which the material flows most easily, that is the direction of rolling. The fact that upon annealing a material with such a rolling texture, a very definite recrystallization texture occurs, is connected with the fact that the places where the crystal lattice is most distorted during slipping, and thus where during annealing, the nuclei of the new crystallites are formed [6]), lie along the slipping planes. Consequently the nuclei also have a definite orientation which is connected with the rolling texture and is manifested in the X-ray picture of the heated material as recrystallization texture. As was explained in the previous article the occurrence of this recrystallization texture is essential for the quality of the Pupin loading strip obtained by further rolling.



a) *b)*

Fig. 4. X-ray photographs of nickel-iron for Pupin cores (direction of rolling horizontal).
a) rolling texture.
b) recrystallization texture.

Still another case is given below in which the

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[2]) Example **4**, Philips techn. Rev. **1**, 60, 1936.

[3]) Example **3**, Philips techn. Rev. **1**, 60, 1936.

[4]) Example **5**, Philips techn. Rev. **1**, 95, 1936.

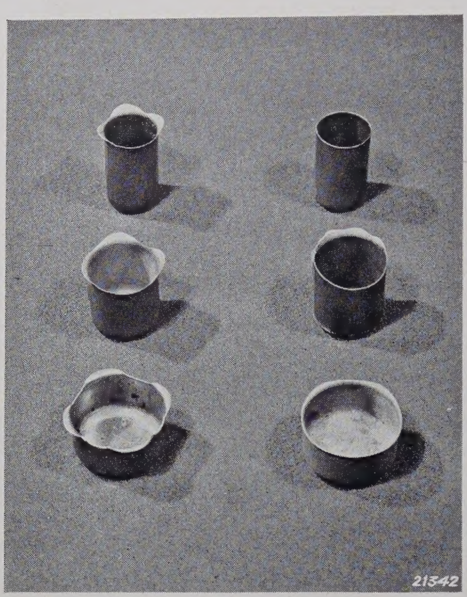
[5]) Example **22**, see Philips techn. Rev. **2**, 93, 1937.

[6]) Cf. example **20**, Philips techn. Rev. **2**, 29, 1937.

X-ray texture examination makes understandable the suitability or non-suitability of a material for a certain purpose.

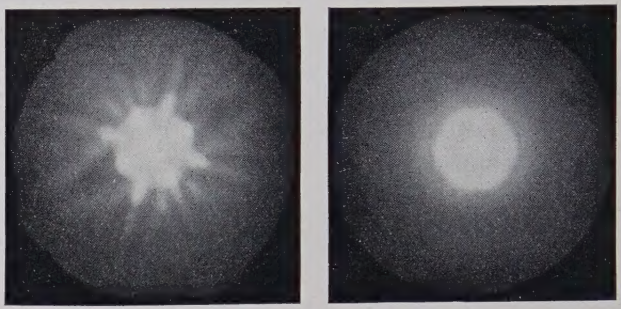
Drawing of chrome-iron cups

In the drawing of cups from round plates of chrome-iron sheet so-called lips usually appear on the rims (*fig. 5*), because the material stretches much more in one place than in another. If this lip formation is too pronounced it leads to the appearance of cracks. In a certain instance this was the case to only a slight degree with old stock material, yet upon the use of a fresh supply much larger lips appeared. Considering that such a phenomenon, according to the literature of the subject, was possibly to be ascribed to anisotropy of the material, X-ray photographs were made of both materials. These are reproduced in *fig. 6*. From the figure it may clearly be seen that in this case also the formation of the lips must be ascribed to the cause mentioned. While photograph 6*b* of the old material is regular in intensity, photograph 6*a* of the new material exhibits alternating dark and light parts. The distribution of the intensity is symmetrical with respect to two mutually perpendicular bisecting lines of the photograph. From this it may be deduced that the properties of the sheet in these two directions will be different from those in the directions lying between (the "45° directions"). From drawing tests on material with such a texture it actually appears that the yield value is unequal in different directions. It is understandable that, as a consequence, the material will flow more in certain directions than in the others during drawing, which may lead to rupture. By a change in the rolling process of this sheet, and particularly by not carrying cold-rolling too far, but alternating it with an intermediate heating, the appearance of a texture was prevented.



a) *b)*

Fig. 5. Cups drawn from round plates of chrome-iron sheet.
a) with } clear lip formation.
b) without }



a) *b)*

Fig. 6. X-ray photographs of chrome-iron sheet.
a) cups with pronounced lips. The material has pronounced texture.
b) cups with only slight lips. The material is quasi-isotropic.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

No. 1142: J. H. de Boer and H. H. Kraak: Die elektrische Leitfähigkeit von dünnen Metall-, insbesondere von Molybdänschichten (Rec. trav. chim. Pays-Bas **55,** 941 - 953, Oct. 1936).

During and after the deposition of thin films of molybdenum the conductivity of the films in relation to their thickness was determined at various temperatures of the support. At temperatures lower than the highest temperature previously reached by the film the changes with temperature are practically reversible. At still higher temperatures, however, the conductivity rises irreversibly. If we consider thin films of metal as intermediate between vapour and solid metal, we may deduce a relative position of the energy levels of the electrons such that the anomalous temperature coefficient of the conductivity becomes logical. This scheme of the energy levels is similar to the scheme for semiconductors according to Wilson.

No. 1143: F. M. Penning: Die Glimmentladung bei niedrigem Druck zwischen koaxialen Zylindern in einem axialen Magnetfeld (Physica **3,** 873 - 894, Nov. 1936).

Following an introduction dealing with the motion of the electrons in a vacuum between coaxial cylinders under the influence of an axial magnetic field, the breakdown voltage and the characteristic of the glow discharge at very low gas pressures are examined. For this purpose, among other factors, the influence of the inclination of the cathode with respect to the direction of the magnetic field and the influence of inhomogeneities of the magnetic field were studied.

No. 1144: W. Elenbaas: Die Elektrodenverluste in der Quecksilber-Hochdruckentladung (Physica **3,** 947 - 953, Nov. 1936).

The sum of the anode and cathode drop is found to increase with increasing vapour pressure and decreasing current, while it depends only slightly upon the phase in the case of alternating current.

No. 1145: F. Coeterier and M. C. Teves: An apparatus for the transformation of light of long wavelength into light of short wavelength. II: The influence of magnetic fields (Physica **3,** 968 - 976, Nov. 1936).

The definition of the picture obtained with the light transformer may be considerably improved by the use of a simple accelerating electrostatic field combined with the magnetic field of a long coil. The rotation of the picture which would otherwise occur is avoided by the use of a permanent ring magnet instead of an electromagnet.

No. 1146: J. F. H. Custers and J. H. de Boer: Elektrostatische und van der Waals'sche Adsorption von Jod an Fuoridschichten (Physica **3,** 1021 - 1034, Nov. 1936).

With a partial covering of a surface of calcium fluoride by iodine molecules of $^1/_2\,^0/_0$ at most, the absorption of light is found to be more than 100 times as great as for free iodine molecules, while the absorption spectrum is shifted toward shorter wavelengths. If more iodine molecules are adsorbed they are no longer held by electrostatic binding forces as were the first molecules adsorbed, but by van der Waals' forces, The absorption coefficient then decreases sharply and passes over into that for free iodine, although the absorption spectrum remains shifted to shorter wavelengths. Upon continually increasing occupation of the surface the maxima of the absorption curves are shifted toward longer wavelengths. This is especially the case with the maximum at the long-wave end. The absorption spectra for iodine adsorbed on strontium and barium fluorides have also been determined, and they were found to be very similar to those for calcium fluoride. In the case of the adsorption in calcium fluoride the spectrum of the iodine molecules is shifted farther toward shorter wavelengths than in the adsorption on strontium fluoride, and in the latter case more than barium fluoride. This supports the contention that the absorption spectrum is shifted more in the presence of a small cation than in the presence of a larger one.

No. 1147: H. Bruining: The depth at which secondary electrons are liberated (Physica **3,** 1046 - 1052, Nov. 1936).

The secondary emission of a surface exhibits a maximum depending upon the velocity of the primary electrons. The decrease in the secondary emission may be explained by assuming that the primary electrons penetrate deeper into the material with increasing speed, so that an increasing proportion of the electrons freed at those depths are unable to reach the surface. By bombarding surfaces of varying degrees of roughness and at various angles of incidence with speedy primary electrons it has actually been ascertained that the secondary emission of a sufficiently smooth surface is greater for shearing incidence than for normal incidence. With primary electrons of 500 volts the average depth to which secondary electrons are freed in a nickel plate is estimated at about 30 Å.

No. 1148: M. J. O. Strutt: Moderne Mehrgitterelektronenröhren (Schweiz. Arch. angew. Wiss. Techn. **2,** 183 - 199, Aug. 1936).

In this lecture given before the Physikalische Gesellschaft in Zürich a survey was given of the modern development of radio tubes with several electrodes. After an introduction dealing with the properties of triodes and pentodes, the tubes with variable amplification were discussed, namely the pentode with a control grid of "variable" pitch and the hexode. Such a hexode may also be used as a frequency changer. A simplified form of such a changer, which unites all functions in one tube, is the octode (six grids). The requirements of little noise and few other disturbances are discussed. Due to the vibrating space charges in such electron tubes a number of interesting effects occur, of which the so-called "induction effect" is discussed in detail.

No. 1149: W. G. Burgers (in collaboration with J. A. A. Ploos van Amstel): An apparatus for "optical" demonstration of some geometrical features of electron diffraction photographs (Z. Kirstallogr. A **95,** 54 - 73, Oct. 1936).

In this article a description is given of the construction and use of an apparatus by means of which different geometrical features of electron diffraction photographs may be shown visually with the help of the so-called reciprocal grating.

No. 1150: W. G. Burgers and F. M. Jacobs: Röntgenographische Spannungsbeobachtungen an Nickeleisenblech (Metallwirtschaft **15,** 1963 - 1066, Nov. 1936).

The reflection of Co-Kα radiations on 100-planes of a recrystallized nickel-iron plate with about 53 atom per cent of iron is very sensitive for small changes in the lattice constant. In this connection an attempt is recorded to obtain some insight into the state of tension which exists in the material of Pupin cores. Information is given about a recrystallization texture with (100) parallel to the axis of a drawn nickel wire.

No. 1151: P. J. Bouma: Vervorming van geluidstrillingen bij voortplanting door de lucht (Ned. T. Natuurk. **3,** 241 - 254, Oct. 1936).

In this article a systematic treatment is given of the various terms ordinarily neglected in the solution of the vibration equations of sound. A discussion is further given of the result obtained by the taking into account in a first approximation of these neglected effects, whereby the occurrence of non-linear distortions is particularly studied in some detail.

No. 1152 *) R. H. Houwink: Kolloidchemie und Kolloidphysik organischer plastischer Massen (Koll. Z. **77,** 183 - 201, Nov. 1936).

The relation between plastic and elastic deformation and the intra and intermolecular forces is discussed. The fundamental difference between pure elastic deformation and that of substances like rubber, in which plastic deformations occur internally, is given. Various types of diagrams for the velocity of flow as a function of the shearing stress are dealt with. Four postulates are proposed for the occurrence of such a highly elastic deformation, which postulates refer chiefly to the four possibilities of storing up potential and kinetec energy in the various bonds. The transition from liquid to solid by cooling and polymerization is discussed. The properties of plastic substances obtained by cooling or polymerization are treated separately for globular colloids and for linear colloids. Additional methods of altering plastic and elastic properties are the formation of links between linear molecules, chemical modification of the surfaces of molecules and the addition of fillers. Finally the significance of the orientation of the particles and of the formation of gels is briefly examined in relation to the properties of the plastic substances.

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*) There is not a sufficient number of reprints available for distribution of the publications marked *. Reprints of the other publications will on request gladly be supplied by the Administratie van het Natuurkundig Laboratorium, Kastanjelaan, Eindhoven.